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NAVAL AIR DEVELOPMENT CENTER WARMINSTER PA AIRCRAFT AND
CREW SYSTEMS TECHNOLOGY DIRECTORATE H J VON BECKH
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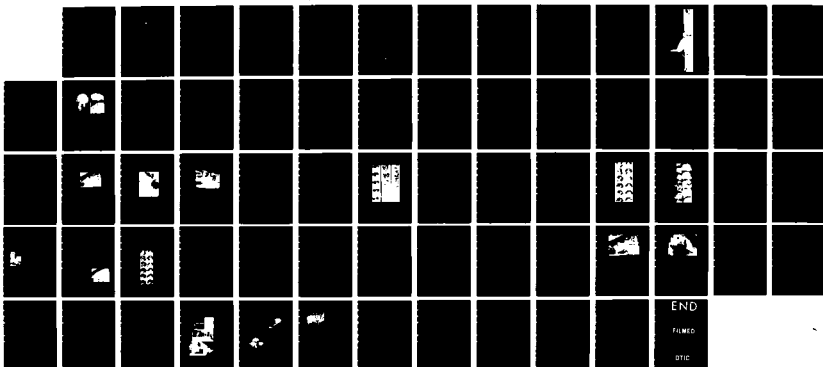
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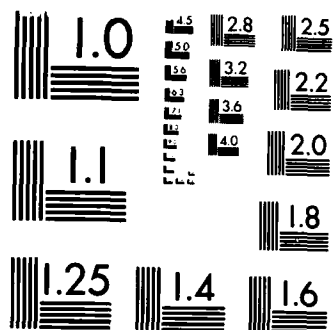
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REPORT NO. NADC-85016-60



THE BEGINNINGS OF AIRBORNE WEIGHTLESSNESS RESEARCH

Harald J. von Beckh, M.D.
Aircraft and Crew Systems Technology Directorate
NAVAL AIR DEVELOPMENT CENTER
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JANUARY 1985

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FINAL REPORT
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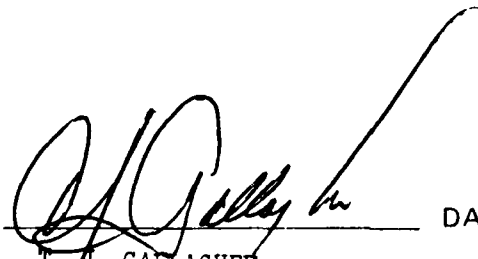
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REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS AD-A160 575			
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; Distribution Unlimited.			
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE						
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NADC-85016-60			5. MONITORING ORGANIZATION REPORT NUMBER(S) NADC-85016-60			
6a. NAME OF PERFORMING ORGANIZATION Naval Air Development Center		6b. OFFICE SYMBOL (If applicable)		7a. NAME OF MONITORING ORGANIZATION Naval Air Development Center		
6c. ADDRESS (City, State, and ZIP Code) Warminster, PA 18974			7b. ADDRESS (City, State, and ZIP Code) Warminster, PA 18974			
8a. NAME OF FUNDING/SPONSORING ORGANIZATION		8b. OFFICE SYMBOL (If applicable)		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (City, State, and ZIP Code)			10. SOURCE OF FUNDING NUMBERS			
			PROGRAM ELEMENT NO.		PROJECT NO.	TASK NO.
			WORK UNIT ACCESSION NO.			
11. TITLE (Include Security Classification) THE BEGINNINGS OF AIRBORNE WEIGHTLESSNESS RESEARCH						
12. PERSONAL AUTHOR(S) H.J. von Beckh, M.D.						
13a. TYPE OF REPORT Final		13b. TIME COVERED FROM _____ TO _____		14. DATE OF REPORT (Year, Month, Day)		15. PAGE COUNT 62
16. SUPPLEMENTARY NOTATION						
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)			
FIELD	GROUP	SUB-GROUP				
19. ABSTRACT (Continue on reverse if necessary and identify by block number) (See reverse side.)						
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS				21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL H.J. von Beckh				22b. TELEPHONE (Include Area Code)		22c. OFFICE SYMBOL

19. ABSTRACT

After World War II an increasing number of aeromedical investigators became interested in the medical problems of Space Flight, particularly its most challenging aspect: Weightlessness. Until 1950 their efforts remained limited to theoretical deliberations and predictions. Beginning in the early fifties, however, researchers began actively to experiment with weightlessness aboard aircraft in vertical diving flights and later by flying Keplerian parabolic trajectories. H.J. von Beckh (1950-1952) made the first weightlessness experiments in aircraft with humans and test animals (water turtles) which were published at the 4th International Astronautical Congress in Zurich (1953) and in the Journal of Aviation Medicine (1954): Von Beckh's experiments showed (1) that the subjects during weightlessness had by no means a strong fall reflex, as predicted by Haber and Gerathewohl in their theoretical paper, in which they evoked the Weber-Fechner Law. (2) The disorientation and lack of neuromuscular coordination occurs only in the first seconds of weightlessness. Later, the control of the vision sense makes aiming movement possible. (3) The incidence of motion sickness was moderate in the weightlessness flights with the Fighter aircraft Fiat G55 and the F 94 C, because the subjects were tied down in the seat and avoided head movements. Later, in the flights with the cargo aircraft C 131, the incidence was considerably higher, because the subjects could move freely and were even allowed to make somersaults. In a later paper (1959) von Beckh showed that weightlessness decreases the acceleration tolerance. This was reconfirmed many years later when the astronauts suffered "orthostatic hypotension" after their return to the earth.

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53 thru 58. The author wanted it that way.
Per Mrs. Dora Huang, NADC/Code 8131

THE BEGINNINGS OF AIRBORNE AEROMEDICAL WEIGHTLESSNESS RESEARCH

by

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FOREWORD

The astronautical pioneers Tsiolkovsky, Goddard, and Oberth first considered the possible effects of spaceflight on humans early in the twentieth century. After World War II, an increasing number of aeromedical investigators became interested in the medical problems of spaceflight, particularly its most challenging aspect: weightlessness. Until 1950 these efforts remained limited to theoretical deliberations and predictions. Beginning in the early fifties, however, researchers began actively to experiment with zero gravity. Weightlessness was investigated aboard aircraft in vertical diving flights and later by flying Keplerian trajectories. Less accurate simulations of weightlessness using immersion and subgravity towers on the ground, complementing the airborne research, yielded additional findings.

This paper examines these early studies, and contrasts the experimental results obtained with the medical data returned in the 1960's when manned spaceflight became a reality.

INTRODUCTION

I was a pilot and a flight surgeon of the German Luftwaffe in February 1940. At the end of World War II I had over five years of experience in Aviation Medicine. After the war I wanted very much to stay in this specialty. It became obvious however that after the war flying in Germany would not be possible for many years, so I volunteered at the Argentine Mission in Genoa to work for the Argentine Air Force.

In Argentina, a country of the southern Hemisphere, many physical phenomena differed from the northern part of our globe. For example, due to the Coriolis effect, the water in a washbowl flows clockwise as opposed to counter-clockwise in the northern hemisphere. This was not a particular bother to transplanted pilots, as was the fact of the sun being in the north direction at noon. At first, this somewhat affected our orientation. In helpful contrast, however, was the Argentine Railroad System. All rails originate in Buenos Aires and go fanlike to the west and by law all the railroad stations had their names painted on the roof of the station in big white letters. One of the most important navigational instruments was a railroad timetable which each pilot had in his cockpit. If a pilot wished to orient his position, he would fly at a low altitude and read the name of the railroad station he was over, consult his timetable and navigate to his destination. This maneuver was called in the pilot's jargon "to buy a railroad ticket."

Soon after my arrival in Buenos Aires, I became a consultant in the National Institut of Aviation Medicine of the Argentine Air Force.

THE PRECURSORS OF ASTRONAUTICS

Authors like Edgar Allen Poe (1809-1847), and Jules Verne (1828-1905) treated weightlessness as an interesting aspect of space flight. But the first authors which brought space flight problems in the scientific sphere were the Russian, Konstantine E. Tsiolkowski (1853-1881), the American, Robert E. Goddard (1882-1945) and the Transylvania-born German, Herman Oberth (born in 1894).

THEORETICAL PAPERS ON WEIGHTLESSNESS

In 1950, the Space Medicine Branch of the Aeromedical Association, and the International Astronautical Federation were founded.

These times are described in detail in my paper in the Journal of Aviation Space and Environmental Medicine (28):

The spectacular advances in rocketry during the 1940's stimulated an increasing number of aeromedical investigators to become interested in the biological and medical aspects of space flight. The great majority of the scientific community, however, remained skeptical as to whether space travel would be possible at all.

Showing great foresight, scientific know-how, and not a small amount of courage for those times, Maj. Gen. H.G. Armstrong organized a Panel Meeting on the topic of "Aeromedical Problems of Space Travel" in November of 1948. The presentations at the meeting, held at the USAF School of Aviation Medicine, Randolph Field, Texas, were made by Gen. Armstrong, Prof. Hubertus Strughold (who even then was regarded as the "father" of space medicine), and the astrophysicist, Dr. Heinz Haber. Gen. Armstrong showed the same foresight a year later when he established a Department of Space Medicine at the School.

At the 20th Annual Scientific Meeting of the Aero Medical Association, held in New York in 1949, two papers were presented pertaining to space flight. The word "space," however, did not appear in the titles because, at that time, "space" was relegated to science fiction writers, and its use would not have been compatible with the serene and dignified atmosphere of the scientific sessions. Thus, the authors, Gen. Armstrong and Dr. Paul A. Campbell, respectively, spoke about "Some Aviation Medical Problems Associated with Potential Rocket Flight" and "Cybernetics and Aviation Medicine."

The negative attitude concerning "space" very likely existed in most countries. As an interesting parallel, I would like to recount a situation that occurred at the same time in Buenos Aires. At the Aeromedical Institut of the Argentine Air Force I conducted airborne studies on the effects of weightlessness producing brief periods of weightlessness by vertical diving flights in an open cockpit aerobatic biplane (FW 44). The duration of weightlessness was severely restricted by the limited maximal allowable diving speed of the aircraft and by the altitude necessary to recover from the dive at a sufficiently high altitude over the airfield. As the experiments involved some risk, the responsible safety officers took a grim look at these studies, and threatened to ground the aircraft and the investigator several times. To obtain weightlessness of longer duration, it was necessary to fly parabolic (Keplerian) trajectories, and this could be accomplished only with a more powerful aircraft. In the formal request to Headquarters, Argentine Air Force, for the assignment of such an aircraft, the official justification also avoided the mention of "space" flight; rather, it emphasized that periods of weightlessness could occur in some air combat maneuvers. The justification reads:

"...combination of diving flights and pull outs into parabolas do occur when fighter aircraft make—for instance—gunnery runs on bombers. The attacking plane penetrates the fighter escort by high-speed diving from a superior altitude, makes its pass at the bomber from below as he pulls out, then evades the bomber's tail guns by another dive. If this parabolic flight path by accident approximates a Keplerian trajectory, the pilot would experience short periods of weightlessness. Thus, it is desirable to investigate whether these periods of weightlessness affect the pilot's neuromuscular coordination and/or orientation, as has been predicted by several authors."

This diplomatic formulation very likely eased the favorable decision of the official at Headquarters, although he may have suspected the real purpose of the flights. The assigned aircraft (Fiat G 55) was deployed with a Fighter Wing at Mendoza, near the Andes Mountains, about 600 miles from Buenos Aires. Only one week after the request had been submitted, this aircraft was ordered to El Palomar Air Base in Buenos Aires. The Aeromedical Institute was notified of the favorable decision when the aircraft had already taken off from Mendoza, so that the investigator had to prepare the protocol and the airborne zero-G instrumentation very hastily.

This rapid assignment of a research aircraft was unprecedented and, for quite a while, was the topic of discussions in the aeronautical circles of Buenos Aires. Jokingly, it was stated that this victory over bureaucratic inertia was only possible because the project was "weightless."

Meanwhile, in the United States, the conception of a space medicine organization merged as a result of a significant meeting. This was the symposium on "Biological Aspects of Manned Space Flight" held at the Medical College of the University of Illinois on 3 March, 1950. Gen. H.G. Armstrong and the late Dr. Andrew C. Ivy, then Vice President of the Chicago Professional Colleges of the University of Illinois, co-sponsored this historic meeting.

This time, the prominent authors no longer had to avoid the word "space," as can be seen from the titles of the lectures: "Space Medicine in the United States Air Force," by Maj. Gen. Harry G. Armstrong USAF, MC; "Multi-Stage Rockets and Artificial Satellites," by Dr. Wernher von Braun; "Physiological Considerations on the Possibility of Life Under Extraterrestrial Conditions," by Hubertus Strughold, M.D.; "Astronomy and Space Medicine," by Heinz Haber, Ph.D.; "Orientation in Space," by Paul A. Campbell, M.D.; "bioclimatology of Manned Rocket Flight," by Konrad Buettner, Ph.D.

The great number of enthusiastic attendees, the spirited discussions, the public response, and the news media coverage were beyond all expectations. Dr. John Marbarger, then head of the Environmental and Aviation Medical Laboratory of the University of Illinois, participated in the organization of the meeting, and edited and published the symposium proceedings in book form at the University of Illinois Press. This book, entitled "Space Medicine—the Human Factor in Flights Beyond the Earth," was soon in its third printing. Thus, for space sciences, the year 1950 can be considered as the breakthrough from the science fiction level to accepted scientific status.

The immediate outgrowth of this successful meeting was that the participants and attendees agreed that an organization was necessary to coordinate the exchange information related to space medical research. It was the consensus that this organization should be within the framework of the Aero Medical Association.

Thus, an "Informal Committee Interested in Space Medicine" was formed. Dr. A.C. Ivy kindly agreed to be the pro tem chairman of the group. The first session was scheduled as a luncheon meeting during the 21st Annual Meeting of the Aero Medical Association in Chicago. Dr. Strughold and Dr. Gauer were asked to make formal presentations at this luncheon meeting in the Palmer House Hotel on 31 May, 1950.

Dr. H. Strughold made the first presentation, which contained the following prophetic remarks:

"It can be predicted that rocket and space flight are in the same state of development as was aviation in 1920, whose field of research, including the medical sciences, experienced an explosive development in the following decades. It appears that the space sciences will develop along similar lines. In order to enable the medical faculty to keep pace with the presumable technical development, it is mandatory to place space medicine on the broadest possible basis and, in this manner, effect a rapid and extensive development."

Dr. Haber summarized the physical characteristics of the high-altitude atmosphere and of sealed cabins. Also, he recommended a formal space medical organization. Drs. O.O. Benson, E.J. Baldes, P.A. Campbell, and R.S. Benford participated in the discussion and agreed.

Following the discussion, a motion was made, seconded and passed, to petition the Aero Medical Association for affiliation as a section. A committee was established to prepare the petition for admission to be submitted to the Executive Council; its membership consisted of Drs. A.C. Ivy, J.P. Marbarger, R.J. Benford, P.A. Campbell and A. Graybiel.

THE FIRST EXPERIMENTAL PAPER ON WEIGHTLESSNESS

During World War II as a pilot flying Junkers 87 dive bombers I experienced that when diving nearly vertical, I had the sensation of free fall and weightlessness during the first three to five seconds of the dive. The object was to begin the free fall with minimal speed and then increase the acceleration to prolong the free fall as long as possible, i.e., until the permissible diving speed was reached. I selected a test vehicle, the Focke-Wulf 44. This was a German aerobatic two-seater biplane, which was fabricated in Argentina and was a very common school plane for primary

instruction. These experiments began in 1950. It was dangerous to pull out at maximal speed (and sufficient time of weightlessness) and to still have sufficient altitude between the ground and the aircraft. (The Base Commander threatened to ground me on several occasions.) With the Fock-Wulf 44, I made two different series of experiments, one with humans, who had to perform a "cross drawing test" during the diving flight, and second, a series of tests with water turtles (see later).

THE ZERO-G METER

The Zero-G meter used in these experiments consisted of an 11-inch long glass tube which was suspended perpendicularly. On the upper extremity was a steel spiral which was fixed on an iron sphere whose diameter was nearly the inner diameter of the glass tube. In the horizontal position, the spiral drew the sphere until a position which roughly corresponded to zero-G and which was marked as such. In the vertical position, the sphere descended to a mark which was designed 1G.

After the weightless phase and before the aircraft produced the high accelerations of the recovery, the instrument had to be placed in a horizontal position to prevent the high accelerations from ruining its sensitivity.

Although the instrument functioned properly, a better zero-G meter was discovered after a series of flights. This so-called meter consisted of a glove or a ping pong ball, suspended before the pilot, and indicating by floating freely whether there was exact weightlessness present giving the pilot the indications necessary to change the flight parabola.

Much later, in 1958, at Holloman Air Force Base, we had a sophisticated device available for weightlessness flights which consisted of two microammeters. When both needles were on zero, then the parabola was exact. The needles, however, had a noticeable time lag, so that the simple glove and ping pong ball "instruments" were generally preferred.

PUBLICATION AT THE 4TH IAF CONGRESS IN ZURICH

I published the results at the 4th International Astronautical Congress in Zurich, August 3-8, 1953; its German title was "Untersuchungen ueber Schwerelosigkeit an Versuchspersonen und Tieren waehrend des lotrechten Sturzfluges" (in English: "Investigations about weightlessness on human and animal Subjects during Vertical Diving Flights"). This was the first experimental weightlessness paper ever published (18). Its enlarged form was published in the Journal of Aviation Medicine in June 1954 (19).

On 20 August 1952, I was invited by Dr. Odoris, the Director of the Department of Physiology of the Buenos Aires Medical School, to speak about my experiments in a lecture open to the public. The title of my lecture was "Physiology of Flights at Extreme Altitudes." At the end of the lecture a distinguished gentleman congratulated me and introduced himself: Colonel Roadman, Air Attachee, American Embassy. He asked me if I could give him a copy of my paper. After properly clearing my paper with the Argentine authorities I visited Colonel Roadman in his office at the American Embassy and gave him the paper. Later he showed me the evaluation of my paper by Dr. J.P. Henry, of the Aeromed Lab in Wright Patterson AFB which stated:

"von Beekh's paper is an example how....ingenuity can replace resources...."

Colonel Roadman later became my superior as Commander of the Aerospace Medical Division.

In 1950 H. Haber and F. Haber had published an article with the title...."Possible Methods of Producing the Gravity-Free State For Medical Research" (9). My wish was to fly parabolas with an aircraft which was available at the airbase in Mendoza. That was the Fiat G 55-B which was similar to the Messerschmitt 109, with which I was familiar.

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Figure 1. The Italian-built Fighter Aircraft Fiat G 55 B which I used for flying Weightlessness Parabolas. The aircraft has an engine of 1450 HP and was similar to the German Fighter Aircraft Me 109, with which I was familiar.

On 31 August 1952, I gave a lecture at the Institute of Aviation Medicine to which Brigadier General Feliciano Zumelzu was invited. General Zumelzu was Cuartel Maestro General de Aeronautica; i.e., he was the Commander of all units of the Argentine Air Force with the exception of the flying units. Also, the surgeon general and his Medical Corps was under him. I described my flights with the FW 44 and stated that it would be desirable to reach a much longer time of weightlessness if I could use a higher performance aircraft like the Fiat G 55. I observed the General during my speech, and he made no favorable indication of my suggestion. After my speech, the General congratulated me but he said nothing about the availability of the Fiat G 55.

I was, therefore, very astonished when I received a telephone call three days later from the Base Commander of the Air Base El Palomar (near Buenos Aires) informing me that a Fiat G 55 aircraft from the base in Mendoza had landed in Palomar and was awaiting my instructions. This rapid decision in my favor was unique in the Argentine Air Force. In the aeronautical environment this rapid decision became well known and sensational. It was humorously said that my weightlessness experiment request was approved so quickly because it was weightless. After the phone call I rushed into a glass blower shop nearby and bought another glass tube for my zero-G indicator, because the glass tube was broken in one of the last Focke Wulf 44 flights (see picture of Zero-G indicator). Then I rushed to the Palomar Air Base. The pilot, Capt. N. Gonzalez, understood the problem of parabola flying immediately and we started the experiments which gave us a zero-G duration of 20 seconds, consequently enabling me to enlarge upon my paper significantly. It was published in the Journal of Aviation Medicine in 1954 (19) under the title "Experiments with Animals and Human Subjects under Sub- and Zero-Gravity Conditions during the Dive and Parabolic Flight."

This paper was the very first in the literature, which contains experimental data of humans and animals under weightless conditions.

It is reproduced in the following article.

Reprinted from THE JOURNAL OF AVIATION MEDICINE,
Volume 25, Pages 235-241, June, 1954

Experiments with Animals and Human Subjects under Sub-and Zero-Gravity Conditions during the Dive and Parabolic Flight

By H. J. A. VON BECKH, M.D.

Buenos Aires, Argentine

SUB-GRAVITY and zero-gravity states are becoming more and more important in aviation, because they frequently occur in high-speed, high-altitude flight. It is therefore necessary to answer the question whether the powers of orientation and muscular co-ordination may be seriously disturbed in these states, as others have suggested. If so, the safety of the pilot and of his crew would necessarily be endangered, as will be seen.

Before World War II, H. von Dänigshöfen described some experiments with sub- and zero-gravity, which he carried out for a period of about ten seconds at a time in vertical dives with his plane.¹ In 1951, Haber and Haber suggested zero-gravity flights with fast flying airplanes along a Keplerian trajectory to obtain gravity free conditions up to about thirty seconds for medical research.¹² This method was successfully employed by Ballinger in experiments with human subjects, as he reported in this JOURNAL.³ Other valuable results were obtained by Henry, Ballinger, Maher, and Simons (1952) by photographing the behavior of animals during sub- and zero-gravity conditions in V-2 and Aerobee rockets.¹³

EXPERIMENTS WITH ANIMALS

Since 1951, the author has been studying the behavior of certain species of Chelonia, notably *Chrysemis ornata* and *Hydromedusa tectifera*, which are found on parts of the South American Continent. These turtles would seem to be especially suitable for studies of orientational behavior and muscular co-ordination, because of their ability to move under water with extraordinary speed and skill in all directions, during their quest for food. The animals belong to an extremely voracious class of water turtles. Under normal gravity conditions, i.e., on the ground or in horizontal flight, they strike like snakes at their food, projecting their S-shaped necks with pin-point accuracy at the bait. They will also snatch a piece of meat hanging from the mouth of another animal. In fact, when they are hungry, they try to pull out the bait which is already in the mouths of other turtles.

For behavioral studies under sub- and zero-gravity conditions several normal animals and one turtle with a permanent injury of the labyrinth were used. This animal had been left for some days by accident in an overheated aqua-terrarium. As a result, he

SUB- AND ZERO-GRAVITY CONDITIONS—VON BECKH

showed a complete loss of orientation, which was particularly obvious in the water. Offered a piece of meat, this *Hydromedusa tectifera* tried to attack it with strong but unco-ordinated movements that contrasted strangely with his normally smooth, swift locomotion. Moreover, when striking, the head of this animal would pass over, under, or to one side of the bait. After two weeks, the turtle slowly began to recover. The improvement was shown by his movements, and later also by his aim in taking the bait. At the end of three weeks from the time of the accident, the animal was able to eat normally. I concluded that this turtle had suffered a permanent labyrinthine injury, from the extreme thermic irritation to which he had been exposed, but that he had then learned to compensate for his loss of labyrinthine cues, by developing his visual orientation.

In order to test the permanence of the injury, I tied a hood over his head. The animal then displayed complete disorientation again, both in and out of the water. He did not even try to displace the hood, as did the control animals. Nor did the latter show any orientational difficulty when they were subjected to the same experiment.

Experiments in the air were then begun with this "adapted" animal, with other *Hydromedusa tectifera*, and with the two *Chrysemis ornata*. The animals were carried in a cylindrical jar, open at the top and filled with water. They were subjected to vertical dives that produced sub-gravity and zero-gravity conditions for as long as seven seconds. During these, the animals were offered samples of meat, either individually with pincers or by

pushing the bait into the jar. The latter procedure was extremely instructive because of the fight that followed among the animals in their attempt to seize the food.

In the transition from horizontal to vertical flight, some brief negative acceleration was produced. At this time the water (and occasionally the animals with it) would rise up, forming an ovoid cupula to a height of 20 or 30 cm. above the top of the jar. However, most of the water would flow back when the jar was lifted to the same height. The acceleration was measured with g-meters in each of the three axes of the plane. These were specially prepared to record values from zero to plus 1 g or minus 1 g.

RESULTS

The results of these flights may be summarized as follows. Only the *Hydromedusa tectifera* without labyrinthine functions, but visually adapted, behaved with complete normality under sub- and zero-gravity conditions. He moved with speed and accuracy, and demonstrated the same skill and ease in eating as on the ground.

The other three turtles, by contrast, moved only a little, quite slowly, and insecurely. They were unable to attack the offered bait. Even pieces of meat that were placed directly in front of their mouths could not be taken, due to their inability to project their heads in an aiming movement. Yet it was obvious to the observer that they were hungry and were doing their best to strike at the bait. Their failure to take it followed the same pattern that had been observed in the case of the injured animal before adaptation took

SUB- AND ZERO-GRAVITY CONDITIONS—VON BECKH



Fig. 1. (*upper right*)—*Hydromedusa tectifera* on the ground in a defensive position. The long S-shaped neck is partly covered by the shell.

Fig. 2. (*left*)—*Hydromedusa tectifera* attacking: The animal strikes at the bait.

Fig. 3. (*lower right*)—The animal in the water bowl has an injured labyrinth but is visually adapted. The hood-covered head is partly visible. The animal is disoriented and swims in an abnormal inverted position.

place. After the return to horizontal flight, all the animals behaved normally. While these symptoms of disturbed orientation and co-ordination gradually diminished after twenty to thirty flights, the improvements was by no means so great that the normal turtles reached the same mobility and eating skill as shown by the "adapted" animal.

DISCUSSION

The experiments described above demonstrate once more that the senses of equilibrium, vision, and kinesthesia provide the means of orientation and co-ordination under normal or sub-

gravitational conditions. During sub-gravity, all the uninjured animals showed considerable difficulty in both orientation and co-ordination. This was exhibited by their inability to aim the neck and head toward an offered bait. The same animals, disturbed by the absence of weight during zero-gravity, became more or less adapted after a certain number of dives (twenty to thirty).

The animal without labyrinthine functions had experienced orientational troubles of a similar kind immediately after the injury, but had become adapted in the following three weeks. During all zero- and sub-gravity

SUB- AND ZERO-GRAVITY CONDITIONS—VON BECKH

flights, he behaved in a complete normal way.

Magnus and de Kleyn (1924) had demonstrated previously that some of the higher mammals, such as cats and monkeys, are able to walk and climb in a normal fashion several days after labyrinthectomy. Moreover, it has been observed that they can even jump, landing precisely on the target.¹⁴ This proves that they "aim steadily at their target by means of optical postural reflexes at first, then bring the body into a corresponding position." The two authors thus cited found no lasting decrement of muscle tonus in these operated animals. Where it was found at all, it disappeared after a while.

Similarly, the *Hydromedusa tectifera*, according to my observations, executes his movements with no less force after labyrinthine injury, but with impaired co-ordination. After adaptation, he then behaved with complete normality on the ground, and he outperformed by far the normal animals under sub-gravitational conditions. This paradox can easily be explained by the dominant role of the optical sense in orientation. It also appears that the labyrinth has only a partial function in the general regulation of tonicities, and may be compensated for by other senses without serious difficulty when the need arises.

It should be noted, though, that in our case adaptation occurred under normal gravity conditions. A decrement of muscle tonus might possibly be found when gravity and weight are reduced or entirely removed for long periods.

Finally, it may be mentioned that the

labyrinthectomized animal in the experiments described by Henry, Ballinger, Maher and Simons (1952) also did better than the normal animal during sub- and zero-gravity conditions. However, no disturbances of co-ordination were observed in those experiments. Hence, it seems to me that water animals of the species employed in my tests are especially suitable for studies of orientation and motor co-ordination in the gravity-free state. The reason is that they ordinarily move in three dimensions, as most animals do only under exceptional circumstances, and they can be impelled to demonstrate their motor efficiency when hunger is used as the motivating drive.

EXPERIMENTS WITH HUMAN SUBJECTS

A series of experiments in visual orientation and muscular co-ordination of human subjects under gravity-free conditions also was performed. In these tests, the subject had to draw crosses in seven small squares, which were arranged diagonally from the left top corner to the right bottom corner of a sheet of paper (21 x 21 cm.) attached to the instrument panel of an airplane. No support was available for the hand of the subject because of the distance between the seat and the panel. The subject was held by his shoulder belts firmly in his seat.

A fighter plane with two seats was used in these experiments. The 1,500-h.p. engine gave a diving speed of about 365 knots. Two kinds of experiments were made. In the first, each subject took the test (1) in horizontal flight, (2) during radial acceleration in the direction from head to feet, and

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(3) during the dive, under sub-gravity and zero-gravity conditions. The tests were made both with eyes open and with eyes closed; and two different

1. During horizontal flight, with eyes open, the crosses were placed in the squares without difficulty.

2. During horizontal flight, with

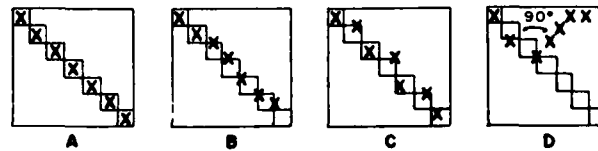


Fig. 4. Cross-drawing test. In horizontal flight: (a) with eyes open, and (b) with eyes closed. During the dive: (c) with eyes open, and (d) with eyes closed.

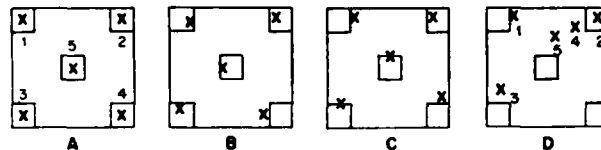


Fig. 5. Cross-drawing test with differently arranged pattern. For details see Fig. 4 a-d.

test forms were employed.

In the second type of experiment, the effect of post-acceleration weightlessness on orientation was investigated. The pilot dived from about 10,000 feet to about 7,200 feet and pulled out of the dive rather abruptly. This maneuver produced a positive acceleration of about 6.5 g, causing the subject to black out. (The pilot was protected against the effects of high acceleration by a crouching position.) Immediately after the pull-out, the aircraft was flown along the ascending arc of the parabola, in which aerodynamic forces are equalized by the power of the engine. In this way, post-acceleration weightlessness was achieved for about twelve seconds.

RESULTS

In the first experiment, the following observations were made:

eyes closed, the crosses were placed diagonally in the prescribed manner with only slight irregularity due to the lack of visual control.

3. During zero-gravity, with eyes open, drawing the marks became difficult. They were made inaccurately, and deviated from the established pattern, although a diagonal direction was generally followed. This of course was due to the visual control.

4. During zero-gravity, with eyes closed, deviation from the diagonal direction was so pronounced that it could not be attributed solely to the lack of visual control. The subjects experienced great difficulty in placing the crosses in the squares.

After the third cross was made, a typical deviation of about 90° toward the right-hand top corner was noted in most cases. However, the execution of this test improved after several

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flights. The person with the longest record in instrument flying showed a very remarkable improvement already after the second flight. The results of one test subject on the two tests are shown in Figures 4 a-d, and 5 a-d.

A further decrease in accuracy was found after the well tightened safety and shoulder belts had been replaced by a loosely adjusted seat belt alone. Besides visual control and positional stability, another psychological factor seems to influence the performance of this test.

The results of the second type experiment may be summarized as follows:

1. During post-acceleration weightlessness orientation was extremely affected. The disturbance occurred shortly after the beginning of the gravity-free state. The subject had the sensation of flying in an inverted position, although no negative acceleration had been present.

2. The black-out lasted longer than after a normal pull-out. Vision was not restored until the plane entered the descending arc of the parabola.

3. Only after the fifth second of weightlessness could the drawing with visual control be started. The crosses then showed the same deviation from the diagonal direction that had been found under sub- and zero-gravitational conditions.

DISCUSSION

Although the interpretation of our results is hampered by the relative small number of experiments, some tentative conclusions may be drawn. Von Diringshofen attributes the

deviation from the line in the drawing test to the dominant tonus of the elevating arm muscles during the state of weightlessness. It also seems to me that the muscular equilibrium of the arms can be better maintained during increased acceleration than with decreased gravity. This observation is in accord with the Weber-Fechner law, as suggested earlier by Gauer and Haber (1950).⁷

Garten (1917) and Strughold (1950) have already pointed out the importance of the tactile sense in maintaining orientation during flight.^{6,16} In this connection, I would like to add that disorientation, due to incorrect labyrinthine cues, can be prevented by the toxic effect of streptomycin on the vestibular apparatus. This effect has been demonstrated by Berg (1949) and by Northington (1950).^{3,15}

So far as visual orientation is concerned, disturbances in the transition phase from the normal to the zero-gravity state may take the form of optical illusions, as suggested earlier by Gerathewohl.^{8,9,10} It seems possible that an illusory effect of this sort may be partly responsible for the deviations in the drawing tests.

As von Diringshofen suggested (1952), the serious disturbances during post-acceleration weightlessness may be caused by poor reaction of the haemostatic regulators in the circulatory system. These are normally adjusted to 1 g.⁴ Moreover, relaxation of the muscles (fall reflex) may cause delay in the flow of blood from the lower parts of the body to the right ventricle (Magnus and Kleyn 1924) with the same result.

The practical side of our problem

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should also be mentioned here. A pilot, pulling sharply out of a dive, may experience greying or blackout. In order to recover quickly, he may push the stick so far that the airplane enters a parabola. In this event, the pilot may become weightless, and his loss of sight and orientation caused by the increasing g's may even be prolonged.

Such a situation will occur when the plane is maneuvering in an air battle. Combinations of dives and pull-outs into parabolas do occur when fighter craft make, for instance, high-side gunnery runs on bombers. The attacking plane penetrates the fighter defense by diving from a high altitude, makes its pass at the bomber from below as he pulls out, then evades the bomber's guns by another dive. In evolutions of this kind during World War II, pilots frequently experienced negative accelerations, weightlessness, and thereby disturbances of vision.

Not only because of its theoretical interest and its application in the future to space flight, but also because it has an immediate bearing on combat flying, the author intends to continue experiments on this problem. It is planned to improve the methods and equipment. Various positions of the head will be used to compare the reactions of the otoliths under sub- and zero-gravity conditions. The optical illusions, predicted by Gerathewohl (1952) during changes of acceleration in the sub-gravity state, also will be investigated further.

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THE LAW OF WEBER-FECHNER

In 1951 H. Haber and S.J. Gerathewohl published a paper entitled "Physics and Psychophysics of Weightlessness" (10). In this paper they evoked the Weber-Fechner Law (The intensity of the sensation is proportional to the Logarithm of the Corresponding stimulus).

The Weber-Fechner Law is generally accepted for the sense of vision and for the sense of audition. For the sense of gravity however, it was never applied because of the complexity of the gravity sense. It is composed by the labyrinthine sense and the proprioreceptors sensory organs.

Haber and Gerathewohl deduced that a range of sensations covering the section from zero to infinity corresponds to the range of stimuli from $g=1$ to $g=\text{infinite}$; a range of sensations covering the section from zero to minus infinite corresponds to the range of stimuli from $g=1$ to $g=0$. Consequently, if we reduce gravity from $g=1$ to $g=0$, we cover a range of sensations which is as large as the range of sensation corresponding to an infinite increase of accelerations starting from $g=1$. The function of the gravity sense becomes particularly critical in the proximity of $g=0$. Haber and Gerathewohl deduced from this erroneously that a sensation of a strong fall reflex will occur, when $g=0$ is reached.

Already in 1953 the French scientist, L. Gougerot criticized heavily the authors in his paper "Loi de Weber-Fechner et variations de la pesanteur apparente" (8) as follows: 1) The Law of Weber-Fechner is well applicable to the sense of vision and audition but not to the sense of gravity because of its complexity; 2) The law of Weber-Fechner gives no proof that a strong fall reflex in weightlessness will occur.

In October 1950 the before-mentioned article from Fritz and Heinz Haber entitled "Possible Methods of Producing the Gravity-free state for Medical Research," appeared in the Journal of Aviation Medicine (9). This paper described how a restricted time of weightlessness could be obtained by flying a vertical ballistic parabola. In the wake of the Habers' paper, a flurry of zero-gravity experiments was begun in both the northern and southern hemispheres (i.e., in both the United States and Argentina).

In 1951, the test pilots, Scott Crossfield and Charles Yeager, made parabolic weightlessness flights with the F-84 aircraft. They noticed not the "strong fall reflex" but the phenomenon of "overreaching": reaching with the arm to a target, on hits a higher point.

Also in my experiments (1950-1953) using the "cross drawing test" (18, 19) when blindfolded, a deviation upwards was noted in all cases. Needless to say, no strong fall reflex was noted.

At the Aeromedical Laboratory in Wright Patterson AFB, R.M. Stanley (13), H.T.E. Hertzberg (12), and others experimented with a modified F-80E aircraft. The aircraft had its nose elongated, allowing an area for a prone couch for the subject. Since 1950, acceleration studies in prone position have been made with this aircraft. In 1951, E.R. Ballinger obtained permission from the Fighter Test Branch to use this aircraft for parabolic weightlessness flights.

The flights were hastily made in summer, 1951. The time of weightlessness averaged 15 seconds (1). Ballinger's report elicited considerable curiosity among its readers who wondered why an aircraft with prone controls was used for zero-G experiments. In fact, the F-80E was selected simply because it was available at the time. His subjects, who were all subjected to the prone position, did not feel at all the "strong fall reflex" predicted by Gerathewohl. Ballinger's report reads: (1):

"...However it was the opinion of the participants that had they been unrestrained and blindfolded disorientation might have been extreme. The tendency of overreach could be easily controlled by looking at the object of the reaching maneuver ..."

In 1954 S.J. Gerathewohl abandoned his prediction of the "strong fall reflex." In his paper (5) he writes:

"We may argue that the application of the Weber-Fechner law is not appropriate to demonstrate the relationship of stimulus to sensation in the gravity-free state..."

Consequently, the Weber-Fechner law disappeared from aeromedical weightlessness literature.

EXPERIMENTS ON WEIGHTLESSNESS WHICH I CONDUCTED IN THE UNITED STATES

At the end of 1956 I accepted an invitation to continue my Zero-G work in the United States. When I came to the USAF Aeromedical Field Laboratory in Holloman Air Force Base, near Alamogordo, New Mexico my commander was Colonel John Paul Stapp, who obtained significant fame with his rocket sled Deceleration Experiments. He made me responsible for the Weightlessness program. Available to me were T-33, F94-C and F-100 aircraft.

My aim was to duplicate exactly what happens in space flight: after the G load of the ascent and insertion in orbit, the weightless phase and after the weightless phase and the transition to reentry, the high G load of the reentry.

The following is a copy of the paper which describes experiments where the alteration of weightlessness and acceleration was studied.

Reprinted from AEROSPACE MEDICINE, Volume 30, Pages 391-409, June, 1959.

Human Reactions During Flight to Acceleration Preceded by or Followed by Weightlessness

HARALD J. VON BECKH, M.D.

DURING the past quarter of a century, aeromedical investigators have succeeded with great ingenuity in simulating on the ground nearly all the conditions and stresses to which the pilot of an aircraft or of a space vehicle could be exposed. Gigantic human centrifuges and rocket sleds have been created to produce high accelerations at controlled rates of onset and decay. Elaborate low pressure chambers now simulate any desired condition of temperature, humidity, and altitude, including even explosive decompression. This makes possible a thorough and more comfortable observation of the subject's physiologic reactions than has been possible in actual flight. However for studying weightlessness, one of the most challenging problems of

space flight, no laboratory has been available which could produce this condition on the ground.

Investigators resorted back to a device which they had nearly forgotten as a research tool: the aircraft. The recent "renaissance" of the aeromedical experimental aircraft, which represents the oldest aeromedical laboratory, has been the result. Here weightlessness has been experienced and observed in the tradition of the first acceleration studies done more than twenty-five years ago before centrifuges for human use were available.

REVIEW OF LITERATURE

In 1950 Haber and Haber¹ described theoretically the possibility of producing the weightless state for medical research by flying segments of a Keplerian ballistic trajectory. Extensive studies of the behavior of humans and animals during the weightless state began at this time. Figure 1 contains a chronological review of the

From the Aeromedical Field Laboratory, Holloman Air Force Base, New Mexico. Dr. von Beckh is technical director of the laboratory.

Presented at the Ninth International Astronautical Congress, Amsterdam, August 25-30, 1958.

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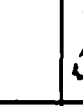



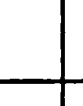
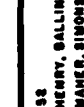
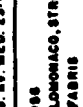
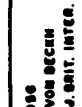
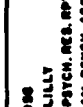


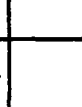





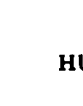

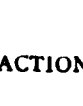
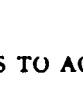



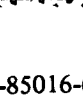



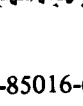



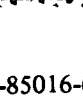
EXPERIMENTS IN WEIGHTLESSNESS				
II IN ROCKETS & OTHER DEVICES				
I	IN AIRCRAFT	IN COORDINATION	IN COORDINATION	IN COORDINATION
	A	B	C	D
1932 HALLINGER J. AV. MED. 23-310				
1933 VON BECKH IN INT. AST. COMM. & J. AV. MED. 20-120				
1936 GERATHEWOHL ASTR. ACTA 6-608				
1936 GERATHEWOHL, STALLING, STRUMWELZ J. AV. MED. 28-7				
1937 GERATHEWOHL, STALLING J. AV. MED. 26-248				
1937 SCHOCK THE SIS, UNIV. OF ILL. DEPT. OF PHYSIOLOGY				
1938 GERATHEWOHL J. AV. MED. 20-136				
1938 SCHOCK MULLERIAN REPORT TN 50-3				
1938 VON BECKH IN INT. AST. CORR.				

Fig. 1. Chronological chart of weightlessness experiments (I) in aircraft and (II) in rockets and other experimental devices. The vertical columns A, B, C, D, represent the different areas of research: neuromuscular co-ordination, disorientation, oculogravic illusions, alternation of acceleration and weightlessness.

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different areas of research in weightlessness. Divided into two parts, it indicates (I) experiments in aircraft and, (II) those conducted in rockets and by other methods such as "subgravity towers," on ships or by immersion in swimming pools. The vertical columns A, B, C, D correspond to the different areas of weightlessness research such as neuromuscular coordination, disorientation, optical illusions and effects of the alternation of weightlessness and accelerations. In this report the numbers in parentheses refer to Figure 1.

In 1953 this author described an eye-hand coordination test,²⁰ (I-A-2) termed "cross drawing test," which consisted of drawing crosses in small squares arranged diagonally across a sheet of paper attached to the instrument panel of the experimental airplane.

Each subject took the test during non-accelerated horizontal flight, during radial acceleration and during the weightless state. The tests were made both with eyes open and with eyes closed. It was shown that during the weightless state, especially when blindfolded, the diagonal direction of the crosses could not be maintained and the line of the drawn crosses showed an upward deflection ("overshoot") because of the changed input-output ratio of the elevating arm muscles. Later it was shown that after several attempts the performance of the subjects improved.

These findings were confirmed by Gerathewohl⁴ (I-A-4) who employed similar tests, consisting of aiming and hitting, with a stylus, a bullseye attached at arms length at the instru-

ment panel, and by Lomonaco, Strollo and Fabris¹² (II-A-2) who used the short duration of weightlessness produced in their ingenious device, termed "Subgravity tower," for performing a similar test. These investigators described an identical "overshoot" upwards and concluded that the subjects learn noticeably on subsequent trials.

Ballinger¹ (I-A-1) formerly had conducted acceleration studies in a modified F-80E fighter. The subject was tied down on a prone bed in the nose of the aircraft. His subjects did not report disorientation or co-ordination troubles. However, he predicted that disorientation or lack of co-ordination could have been extreme if the subjects had been deprived of visual control and of adequate restraint.

Henry and his associates⁸ (II-B-1) carried out most outstanding investigations during rocket flights with the V-2 and Aerobee rockets. Heart rate, blood pressure, and respiration rate were telemetered to a ground station and a motion picture camera photographed the behavior of the test animals.

It was shown that a normal mouse during weightlessness was confused when floating freely in the compartment. Another mouse, whose inner ear was previously destroyed, was less disturbed because it did not receive any labyrinthine cues either true or false. Besides that, the mouse had learned after the labyrinthectomy to replace the missing information from its inner ear by the sense of vision.

This author²⁰ (I-A-2) reported similar findings which were obtained in subgravity flights with water turtles (*Hydromedusa tectifera* and *Chrysemis ornata*). These animals were

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especially suitable for studies of orientational behavior and neuromuscular co-ordination because of their ability to move under water with extraordinary speed and skill in all directions during their quest for food. They strike like snakes at their food, projecting their S-shaped necks with pin-point accuracy at the bait. It was shown that during the weightless state these animals were incapable of striking accurately at the bait. When striking, their heads passed over, under, or to one side of the bait. Only one turtle, without labyrinthine functions, but already visually adapted, behaved with complete normality during the experiments.

Gerathewohl³ (I-B-3) analyzed the subjective impressions of numerous persons during the weightless state: one-fourth of the subjects suffered severe discomfort and nausea; half of them were comfortable and reported even feelings of exhilaration and pleasantness; another fourth had intermediate reactions as slightly disagreeable motion impressions such as tumbling, falling, or being suspended in an inverted position, but only moderate nausea. Gerathewohl and Stallings⁶ (I-C-7) and Schock¹⁶ (I-C-8) contributed valuable studies of optical illusions, termed oculo-gravic illusion. A luminous target as well as a visual after-image, observed in the dark, seemed to be displaced upwards during the weightless state. In consideration of the importance of visual information in the weightless state these illusions could possibly present inconveniences in space flight.¹⁶ A further contribution was made by Gerathewohl and Stallings⁶ (I-B-5) and by Schock¹⁶

(I-B-6) studying the labyrinthine posture reflex (righting reflex) in cats, showing that after a certain duration of weightlessness this reflex ceased to function.

Lilly,¹¹ Margaria,¹³ Schock,¹⁶ and Knight¹⁰ (II-B-4 to 7) succeeded in simulating the weightless state to a certain extent by immersion in water. Applying Archimedes' principle, a subject immersed in a fluid of about the same specific weight is in a kind of weightlessness relative to the surrounding medium. Tilting the person back into an approximate horizontal position, the so-called "blind spot" of the otoliths could be reached and only a minimum of labyrinthine cues would be emitted.

Considering the last column of Figure 1, Alternation of Acceleration and Weightlessness, we see that this area, when compared with the others, was the least investigated.

In 1953 this author included in his early series of experiments certain flights in which the pull-out before entering the weightlessness parabola, which normally does not exceed the 2-G value, was made at high speed and so abruptly that G values of up to 6.5 G resulted.²⁰ (I-D-2). Control runs were made with the same high G pull-out, but without subsequent weightlessness, and instead were followed by unaccelerated horizontal flight. It was found that blackout lasted longer and discomfort and disorientation were stronger when the recovery from the G-stress took place in the weightless state. After this early observation no more airborne experiments on alternation of weightlessness and accelerations were reported, until

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the Soviet IGY release¹⁹ about *Sputnik II's* passenger, Laika (II-D-8) stated that "the accelerated heart rate of the animal, produced by the acceleration of the thrust, returned gradually to the normal rate after the entry into the weightless state. It took, however, about three times as long for the number of heart beats to reach their initial values, as it did in laboratory experiments, when the animal was subjected to accelerations similar to the launching accelerations."

The aspects of alternation of acceleration and weightlessness have today a special importance because this condition will occur during the ascent and the re-entry of a rocket vehicle. In biosatellite experiments the subject will have to endure an accelerative phase from the launching until the burnout of the engine. The transition from this powered ascent to weightlessness will be very abrupt because the designers prefer an abrupt burn-out to a gradual one. On the other hand, during orbital and space flights the subject would stay for hours, days, or weeks in the weightless state, and during the re-entry would again be exposed to considerable G loads.^{2,9,24}

The author in his early experiments termed the pattern flown as "post-acceleration weightlessness." However, under these new circumstances, inasmuch as the reactions to accelerations with preceding or following weightlessness are to be studied, an inversion of the nomenclature seems more convenient: pre-weightlessness accelerations for the ascent patterns and post-weightless accelerations for the re-entry patterns. Because of the importance of the problems in con-

sideration of space flight, fifty-one subgravity flying missions of the overall weightlessness program of ninety-eight missions were performed in the study of pre-weightlessness and post-weightlessness accelerations.

METHODS

Aircraft.—The test vehicle was a Lockheed F-94C two-place jet propelled interceptor aircraft, powered by a Pratt-Whitney J-48-P-7 engine, developing with after-burner a maximum of 8,750 pounds of thrust. Preliminary experiments showed that in the two-place, supersonic fighter-bomber F-100F, much longer durations of weightlessness could be obtained. However, the different behavior of fluids in the weightlessness state causes functional difficulties in the fuel, lubrication and hydraulic reservoirs, and in its sensitive engine, which are more pronounced than in the less sensitive F-94C engine. The author participated in one F-100F mission in which subgravity parabolas of limited duration were authorized. During these maneuvers, oil and hydraulic pressure dropped critically, and further attempts to fly ballistic trajectories in this aircraft were discontinued. At the same time the indicated values of the liquid oxygen gauge and the oxygen-pressure gauge gave reason to believe that conventional liquid oxygen converters would not function satisfactorily in zero G conditions of longer duration.

Flight Patterns.—In the earlier series of experiments²⁰ (I-D-2) high radial accelerations of up to 6.5 G were produced only by a sharp pullout for

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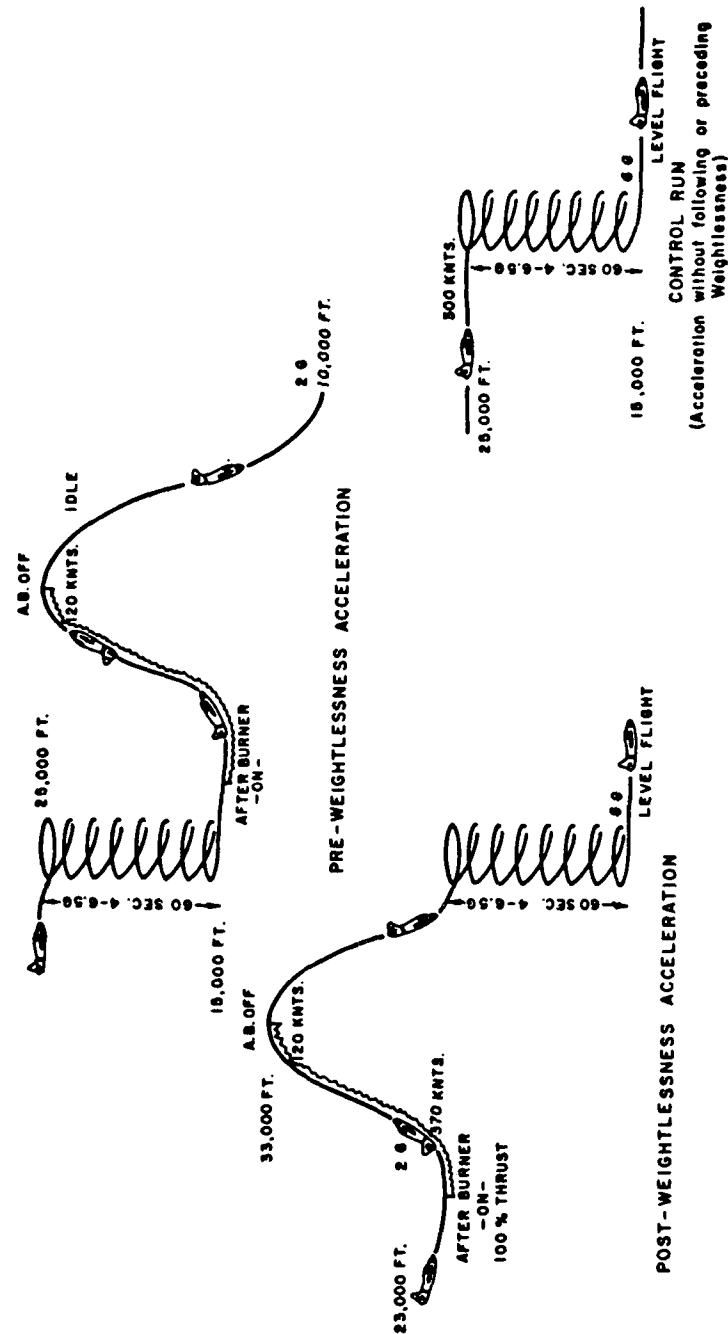


Fig 2 Flight patterns used for simulating the accelerations of thrust and reentry followed or preceded by weightlessness.

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a duration of from 5 to 8 seconds. In these experiments, however, it was desirable to simulate as nearly as possible, the conditions of rocket take-off and re-entry. Therefore another high centrifugal G load-producing pattern was adopted in which periods of from 4 to 6.5 G accelerations were obtained by flying continuous steep turns. Giving up altitude during these turns helps in dosifying and maintaining the desired G values. These maneuvers were termed "diving spirals," (Fig. 2).

The weightless state was obtained for periods of from 35 to 45 seconds by flying Keplerian ballistic trajectories. These patterns were combined in the following flight program: the pattern of pre-weightlessness acceleration, simulating the thrust of a rocket vehicle, and the weightlessness following burnout, was produced in the aircraft by a diving spiral of 40 to 60 seconds duration, which was initiated at an altitude of 25,000 feet and followed by a subgravity trajectory. These diving spirals are completely controlled maneuvers producing centrifugal forces and, because of the apparent similarity of the graphs, should not be confused with spins. The loss of altitude during the spirals was approximately 10,000 feet.

Post-weightlessness accelerations, simulating conditions which would occur during re-entry into the atmosphere after orbit or true space flight, were produced by a Keplerian trajectory initiated at 23,000 feet, reaching the apogee at 33,000 feet, and a subsequent diving spiral. A control pattern was flown, consisting of the diving spiral followed after the pullout by

unaccelerated horizontal flight. This pattern established the G tolerance and subject's reactions to accelerations, when weightlessness was not involved. All spirals during a given mission were flown at the same number of G and the same duration. The sequence of these three patterns was changed adequately from mission to mission, to make sure that fatigue in the patterns flown later in the same mission could not jeopardize the correct evaluation of the observed reactions and symptoms.

The subject was instructed to sit upright and to avoid straining or "fighting the G," while the pilot was protected by an anti-G suit, and was allowed to increase his G-tolerance by crouching forward. In this way it is possible to black out the subject, while leaving the pilot in full possession of his senses and in control of the aircraft.

INSTRUMENTATION

G Registration.—In the pilot's cockpit close to the instrument panel was a visual display, designed by Schock and Simons,¹⁴ consisting of two microammeters with a range of 25-0-25 microamperes connected to a set of sensitive Statham accelerometers with a range of ± 0.5 G, which were fixed to the airframe. Each division on the microammeters is equivalent to ± 0.014 G. If the needles of both microammeters were on the zero mark, the pilot knew that his trajectory was exact.

Another set of sensitive accelerometers was fixed to the subject with a chest band, to provide recording of accelerations actually experienced by

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the subject. The output of these accelerometers was fed, together with the other data, into a sensitive galvanometer-type oscillograph recorder (Midwestern 560). In several flights a second conventional accelerometer and a stop watch were added in the subject's cockpit, and both were photographed by the motion picture camera. Their function will be mentioned later.

*Electrocardiography and Galvanic Skin Resistance Recording (GSR).—*The instrument rack in the subject's (rear) cockpit (Fig. 3) contained an ECG amplifier (Grass, P-5), a dermo-ohmmeter (Yellowspring-Fels, 22-A, airborne), the recording oscillograph, and battery power supplies. Two ECG electrodes were placed

the chest; the other on the right ankle. The GSR electrodes were applied to the sole of each foot. All five electrode

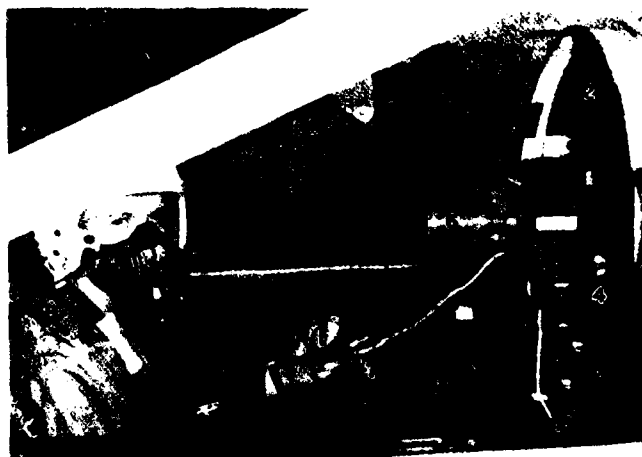


Fig. 3. Subject before takeoff with recording switch (1) in left hand. Shown also are (2) aluminum foil with high reflective qualities to reduce changing light conditions during diving spiral and aid photography; (3) oxygen regulator; (4) oscillograph; (5) electrocardiogram; (6) camera with wide angle lens; (7) quick-release plugs for leads of electrodes; and (8) GSR dermo-ohmmeter.

on leads were united to one cable. A quick release plug was provided between the subject and the amplifier, to avoid hazard or delay in case of emergency ejection.

Cinematographic Observation.—The subject was photographed continuously during the maneuvers by a motion picture camera (Bell & Howell, B-1A) with a wide-angle lens (Wollensack, F: 1.5, 89 degree). At the same time the camera photographed the accelerometer and stop watch (Fig. 4). The subject indicated with his fingers the G values, as transmitted from the pilot through the aircraft communication system. Greyout was shown by waving

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hand movements. All this helped in the chronological reconstruction and evaluation of the physiologic reactions leg (Fig. 5) and the aircraft was in constant communication with a ground station from which the experimenter



Fig. 4. Subject in cockpit, showing mounting of clock (at left upper arm) and accelerometer (right) for use in analysis of motion pictures.

of the subject and to co-ordinate this data with the information of the recorded voice.

Voice Recording.—Pilot, subject and experimenter were in continuous radio communication. The subject was indoctrinated to describe his impressions and his symptoms into the microphone. He carried a miniaturized tape recorder (Mohawk, BR-1) on his left

leg (Fig. 5) and the aircraft was in constant communication with a ground station from which the experimenter could speak to the pilot and subject. The entire conversation was recorded both on the ground and on the subject's tape recorder. This assured preservation of a verbal record even in case of radio failure.

The two way radio installation gave the opportunity to initiate also some psychologic studies. From the ground station, a research psychologist asked test questions concerning word associa-

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tions, inverted number repeating, syllable completions, and drawing tests. The responses were compared strain when they were exposed to a G load immediately after the weightless state. Two subjects, who did not



Fig. 5. Pre-flight preparation of subject. On the chest belt (1) is a sensitive accelerometer for recording G values near the zero mark, and (2) on left leg is miniaturized tape recorder to assure preservation of verbal data in case of radio or ground-station recording failure.

to others which had been recorded on the ground before and after the flight.

RESULTS

In fifty-one missions of more than 200 weightlessness and acceleration patterns, eleven different subjects experienced pre-weightlessness and post-weightlessness accelerations. The subjects included two experienced jet pilots, two persons who had never flown previously, and seven others of intermediate flying background as pilots or observers. Figure 6 is a summary of these missions.

Post-Weightlessness Acceleration.—The subjects experienced higher

blackout during the control run at 5 G, blacked out during the post-weightlessness acceleration pattern at 3.5 and 4 G, respectively. Three subjects who blacked out at 5 G during the control run blacked out at lower G values and at shorter G duration in the post-weightlessness acceleration pattern.

One subject who tolerated 5 G in the control run without visual impairment, blacked out in post-weightlessness acceleration pattern at 3.5 G and lost consciousness at 5 G. Subjects who did not black out either in the control run or in post-weightlessness acceleration, nevertheless reported stronger discomfort during the latter.

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This was also observed in the cinematographic records.

Pre-Weightlessness Acceleration.—It requires a special technique to re-

—The data showed a drop in resistance 25 seconds before the G load was initiated when the pilot indicated that the altitude to initiate the spiral had been reached by saying "ready to go."

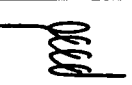
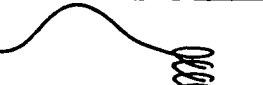

																															
SUBJECT	NUMBER OF MISSIONS	CONTROL RUN					POST-WEIGHTLESSNESS ACCELERATION										PRE-WEIGHTLESSNESS ACCELERATION														
		DISCOMFORT	VISUAL IMPAIRMENT	SUBSTERNAL PAINS	LOSS OF CONSCIOUSNESS		WEIGHTLESS PHASE					ACCELERATIVE PHASE					ACCELERATIVE PHASE					WEIGHTLESS PHASE									
							DISCOMFORT	DISORIENTATION	SUBSTERNAL PAINS	NAUSEA		DISCOMFORT	VISUAL IMPAIRMENT	SUBSTERNAL PAINS	LOSS OF CONSCIOUSNESS		DISCOMFORT	VISUAL IMPAIRMENT	SUBSTERNAL PAINS	LOSS OF CONSCIOUSNESS		DISCOMFORT	DISORIENTATION	SUBSTERNAL PAINS	NAUSEA						
J. F.	12	+										++	+				+														
C. L.	8	+									+	++	+				++	++				+++		++	++	+					
N. B.	6	+										++	+				+														
C. M. C.	6	+										++	+				+	+													
J. B.	5	+	+									++	+++		++		+	+				+++	+	++		+					
E. D.	4	+	+									++	++				++	+				++	+	++		+					
H. C.	4	+										++					+						+	++							
L. B.	2	+	+									++	+++				+	+													
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R. M.	1	+										+					+														
E. A.	1	+										++					+						+								

Fig. 6. Summary of 51 missions.

strict the transition phase, from the G-producing spiral to the weightlessness trajectory, to a duration of less than five seconds. This was not always possible. In the missions in which this transition period was short enough, however, subjects reported unusual symptoms of longer duration of blackout (three subjects), generalized discomfort (four subjects), chest pains (three subjects), and pronounced disorientation (four subjects)

Galvanic Skin Resistance Recording.

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(Fig. 7). During the acceleration the GSR returned to its initial value. In the transition phase to weightlessness a sharp drop appeared, but with the onset of weightlessness an increase took place again. After the final pull-out, i.e., during unaccelerated horizontal flight, the resistance rose steadily to its initial value.

It is too early to draw conclusions about specific responses to weightlessness and its transition phases. In the run illustrated in Figure 7, marked decrease in GSR occurred with anti-

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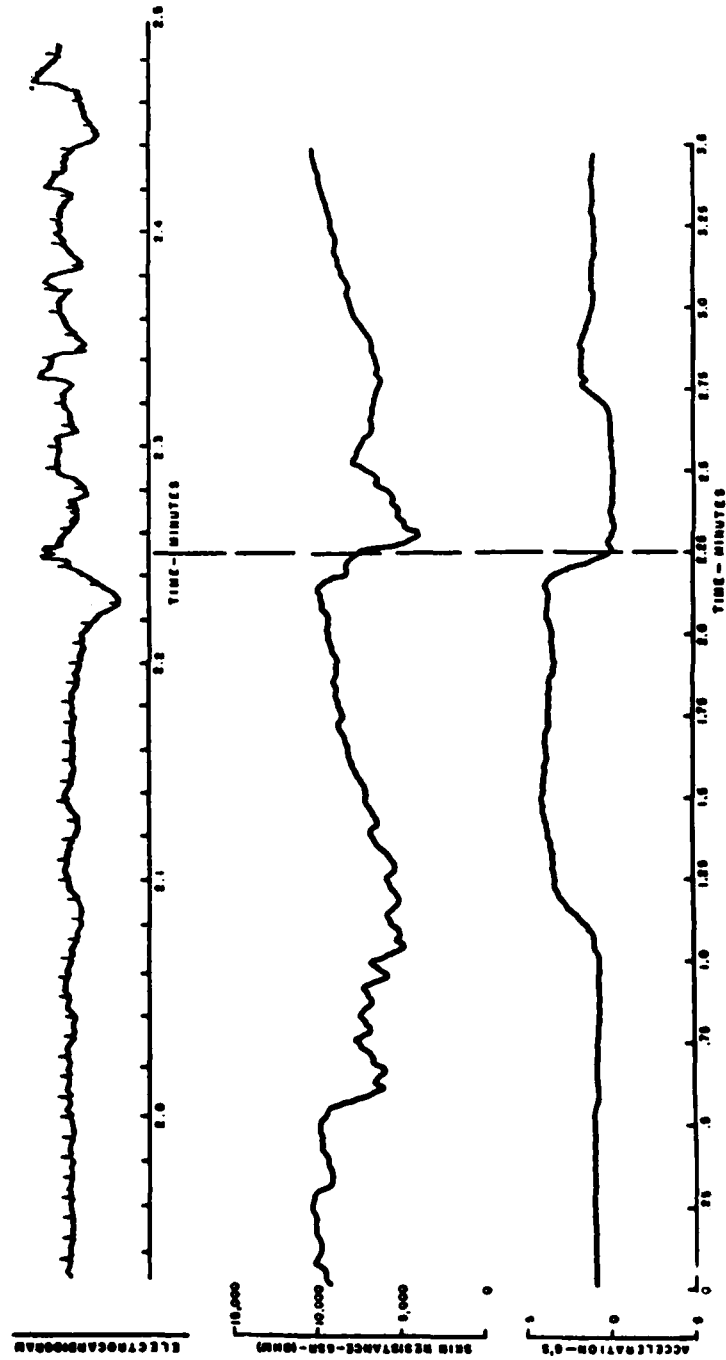


Fig. 7. Electrocardiogram, galvanic skin response (GSR) and acceleration, vs. time.

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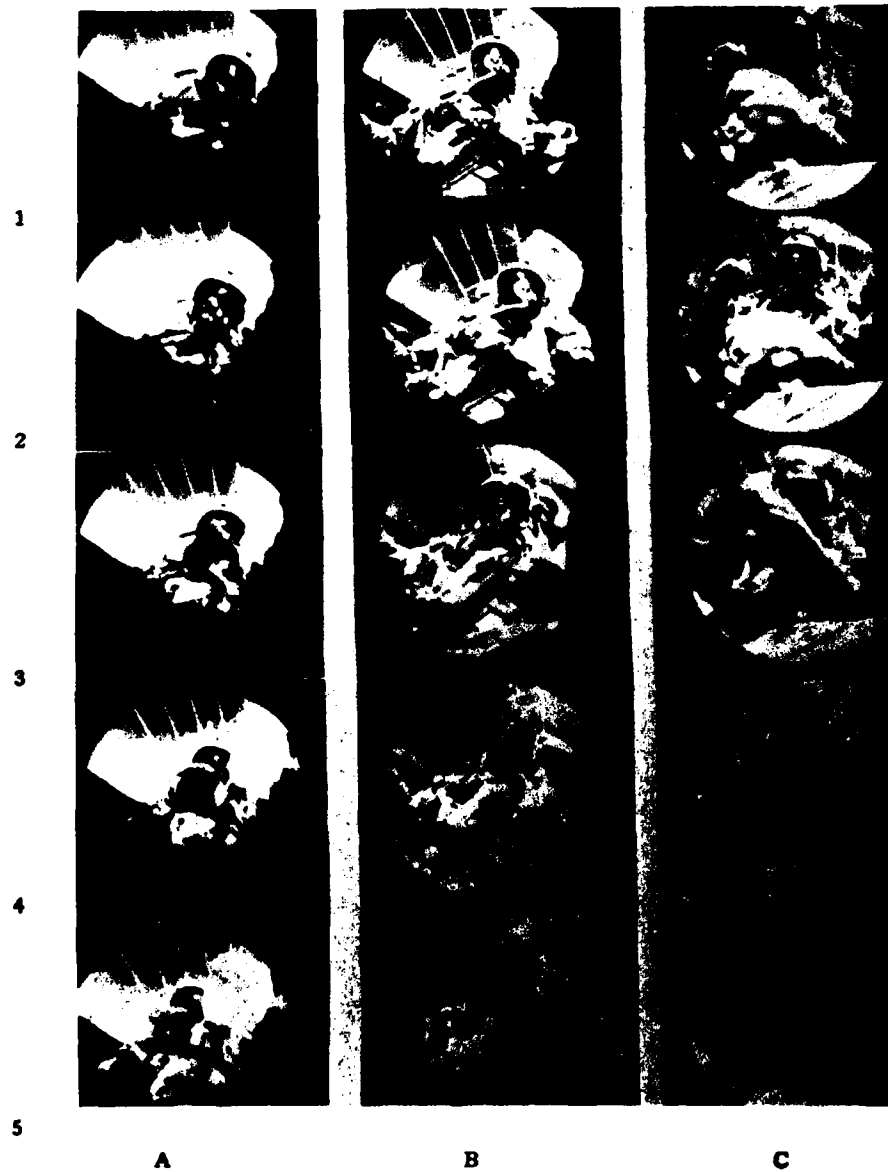


Fig. 8. Motion pictures taken in flight awakening in weightlessness. Column A: Frame 1: subject is asleep, leaning against the cockpit wall. Frames 2-5: awakening. Column B: Frames 1-5: lifting hand to raise dark visor of helmet; and Column C: Frames 1-3: reconnects with difficulty the plugs of helmet earphones; and frames 4-5: disorientated, tries to hold on to the cockpit to maintain some sort of normal posture.

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cipation of maneuvers and change of intensity of gravitational cues which also can be considered as warning messengers of a new gravitational situation. Such decreases are generally associated with increased levels of alertness. Specific responses to the weightless state "per se" could not be observed.

Disorientation.—A supplementary problem occurred in our test series and should be reported here, though it is not directly associated with alternation of weightlessness and accelerations. Simons,¹⁸ during his balloon flight *Manhigh II* experienced marked disorientation on awakening from one of his short periods of sleep, and required several seconds before he was aware of his situation. This observation suggested an investigation of the impressions of a subject who is awakened during the weightless state. A prospective *Manhigh III* subject was selected for this experiment. He went without sleep for 48 hours. After a full breakfast, which increased his sleepiness, he entered the rear cockpit of our experimental F94C aircraft. He unhooked his headset at 11,000 feet, so as not to be disturbed by the conversation of the pilot, tower, and experimenter. Twenty-five minutes after takeoff the subject fell asleep, leaning against the right side of the cockpit (Fig. 8). A string was fixed on his left wrist, which the pilot could pull to awaken him. The pilot avoided any rough maneuvers. The aircraft was then flown in a zero G trajectory and the subject was awakened. His first impressions upon awakening were that his arms and legs "were floating away from him" so that he felt a desperate

need to pull them back toward his body to maintain some sort of normal posture. He tried to hold on to the canopy and some part of the cockpit. He could not orient himself. He is a pilot of over 500 jet hours and had not experienced such pronounced disorientation previously.

DISCUSSION

Delayed recovery from black-out and increased discomfort caused by pre-weightlessness acceleration was first observed by this author in 1953.²⁰ Similar data concerning delayed return to normality of phenomena induced by the previous accelerative phase was reported¹⁹ in the tachycardia of Laika in *Sputnik II* which lasted three times longer than in previous centrifuge runs when weightlessness was not involved.

Three interpretations of these observations come to mind. First, it could be assumed that the complicated synergism of the autonomic cardiovascular pressoreceptors and pressoregulators is "calibrated" for function in a normal one G field. In zero G conditions some disorder or "confusion" of these complicated reflex mechanisms could be expected. This speculation seems to be supported by our finding that the heart rate, after the accelerative phase of the control run, returns to the initial value and remains at this value. When the acceleration is followed by the weightless state, however, the return to the initial value takes place more or less after the same length of time, but the heart rate continues fluctuating up and downwards for a certain period (Fig. 9). This possibly could correspond to the

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time necessary for the cardiovascular reflex mechanisms to adjust to the unaccustomed zero G conditions. The native, contradictory to the former one. After the accelerative phase a large quantity of blood returns to the

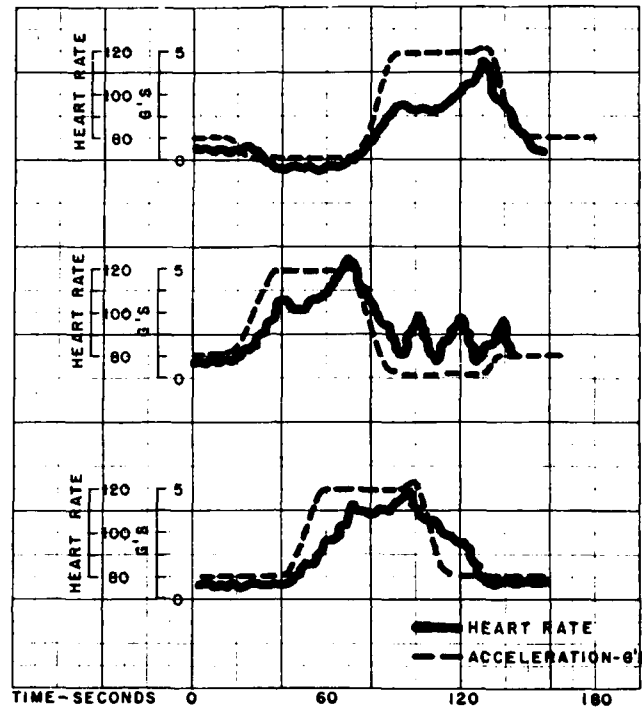


Fig. 9. Acceleration and heart rate vs. time during post-weightlessness acceleration (above), and pre-weightlessness acceleration (center), and control run (below).

difference in the heart rate patterns between data from *Sputnik II* and our experiments may be explained by the higher accelerative load and the additional stress of noise and vibration in the *Sputnik* flight.

Second, delayed recovery and generalized discomfort might be caused by the general relaxation of the muscles during the weightless state. This would cause delay in the return of venous blood to the right ventricle.

Third, we could assume an alter-

right heart producing the phenomena of overfilling, which would explain the cardiac disfunction and substernal pains experienced by three subjects.

A series of roentgenograms, made during the transition phase, might explain these observations, but the installation of radiographic equipment in a modern fighter aircraft, equipped with ejection seats, is not so simple as it was twenty years ago in the experimental Heinkel He-70.²³

Referring to the post-weightlessness

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acceleration findings, it seems rather logical that a subject who has been in the weightless state, even for a short period should evidence greater strain when G loads are imposed. In the evaluation of both groups of experiments we must consider that in our experiments the subject was exposed to head-foot accelerations. In manned space flight, however, the location of the subject would be such that the main acceleration of thrust and reentry would act in a transverse direction. For technical reasons it was not possible to locate our subjects in supine position. Also, the G values obtainable in our experimental aircraft would not have been high enough to cause major discomfort in the less "vulnerable" supine position, and we would not have had at our disposal such adequate parameters as blackout for comparing the reactions of the different conditions. We can assume also that in supine position discomfort and impairment thresholds would be lowered and orientation and blood pressure regulation would be equally affected (Figs. 10 and 11).

Because there is a decreased acceleration tolerance every effort must be made to reduce G loads to a minimum. Despite the fact that a subject is positioned transversely to the longer axis of the vehicle and, therefore, protected against the acceleration of the thrust, there exists the possibility that by imperfections of the automatic guidance systems, especially in the gliding reentry patterns and in emergency separations of the capsule from the vehicle, high G loads could be produced. This G force would act in the vulnerable longitudinal axis of the

subject. One may recall the formerly described principle of multi-directional G protection²² which would protect the subject against severe accelerations with continuously varying direction, rate of onset and intensity.

CONCLUSIONS

Alternation of weightlessness and acceleration results in a decrease of acceleration tolerance and of the efficiency of physiologic recovery mechanisms. This indicates that acceleration thresholds of reversible and irreversible injury will be lower in space flight conditions than in the one G field of man's earthly environment. Defects of circulation, muscular effectiveness, vision, and of conscious judgment will occur at lower acceleration values and will probably continue for longer times than they do under present normal flight conditions. In an astronomical venture depending upon the skill of a human pilot, a blackout, lapse of judgment or even the slightest reduction in efficiency at a crucial time, could undoubtedly cause the failure of the mission.

The implications for planning of manned space flight are, first, that thrust values and reentry profiles must take the lower acceleration tolerance into consideration and, second, that adequate G protection must be designed for the pilot to prevent dangerous effects of high acceleration.

ACKNOWLEDGMENT

These experimental flights were possible only by the thorough co-operation of numerous services of the Air Force Missile Development Center, Holloman Air Force Base, New Mexico. The author is especially

AEROSPACE MEDICINE

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A

B

Fig. 10. Two subjects during post-weightlessness acceleration showed more severe effects than in other runs producing the same G load without preceding weightlessness. Column A: frames 1-2: weightless state; and frames 3-6: under increasing acceleration. Column B: frame 1: weightless state; and frames 2-6: under increasing acceleration.

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A

B

Fig. 11. Subject during post-weightlessness acceleration and pre-weightlessness acceleration. Column A: Subject in post-weightlessness acceleration increasing to 5.5 G. Column B: Subject in the transition phase from an acceleration peak of 6.5 G to weightlessness. Frames 1-2: 6.5 G; frames 3-5: recovering from G stress during weightlessness.

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indebted to the Fighter Test Group, Maintenance Services, Photo Lab Services, and Messrs. C. M. McClure, H. Castillo, A. Brown, and J. C. Bunn for their efficient help in developing and monitoring the instrumentation and recording devices. Last, but not least, I want to recall the co-operation of the subjects of these missions, who volunteered for this task, which was for them not always very comfortable.

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WEIGHTLESSNESS AND SPACE FLIGHT

Three months earlier, in February 1959 appeared in the Journal "Astronautics", the paper "Weightlessness and Space Flight" (24). Its last paragraphs state:

Other problems could arise in space flight of longer duration. Extended weightlessness may very likely lead to lessened muscle tone and strength. Therefore, devices similar to ergometers should be used to exercise the muscles during space travel.

Other inconveniences can be expected for the circulatory system. The heart, used during weightlessness to transport the blood column without the force of gravity, would need a certain time for adaptation after reentering the gravity field of the earth or another planet.

One example can help illustrate this situation: A person who has been ill and confined to bed for several weeks and then stands up for the first time is likely to experience a so-called orthostatic collapse, because here also the cardiovascular system has lost the ability to compensate for the hydrostatic forces of 1 g.

The article predicts that the heart, used during weightlessness to transport the blood column without the force of gravity would need a certain time for adaptation after reentering the gravity field of the earth or another planet. So was predicted the latter called "Deconditioning Effect of Weightlessness" which appeared much later after the Astronaut's Schirra flight who experienced orthostatic hypotension after he returned after his orbital flight to the earth.

The whole paper is reproduced in the following:

Weightlessness and space flight

Aeromedical aircraft experiments indicate that astronauts' difficulties will not lie in the weightless state itself, but rather in aggravation of other conditions, which, in combination, could pose problems

By Harald J. von Beckh

AEROMEDICAL FIELD LABORATORY, HOLLOMAN AIR FORCE BASE, N.M.



Harald J. von Beckh, assistant chief of the AF Aeromedical Field Lab's Space Biology Branch, graduated with an M.D. degree from the Univ. of Vienna in 1940. Already a pilot at this time, his primary interest was directed towards aviation medicine. In 1941, he was assigned to the staff of the Aeromedical Academy in Berlin, where he lectured for student flight surgeons. Shortly after WW II he went to Buenos Aires, Argentina, where he lectured in postdoctoral courses at the National Institute of Aviation Medicine. He devoted the major part of his research activities to the study of human reactions to weightlessness and is remembered for pioneer work in airborne experiments with human and animal subjects. Besides numerous papers in aeromedical and aeronautical journals, he published in 1953 the textbook "Physiology of Flight" (in Spanish), a work which emphasized the medical aspect of space flight. An honorary member of the German Rocket Society, since 1952 he has been director of the Space Medicine Department of the Argentine Interplanetary Assn.

DURING the past quarter century, aeromedical investigators have with great ingenuity succeeded in simulating on the ground nearly all the conditions and stresses to which the pilot of an aircraft, or of a space vehicle, could be exposed. Gigantic human centrifuges and rocket sleds have been created which produce high accelerations at controlled rates of onset and decay. Elaborate low-pressure chambers now simulate any desired condition of temperature, humidity, and altitude, and can, under safe control, produce even explosive decompression.

Equipment of this type makes possible more thorough and more comfortable observation of the subject's physiological reactions than has been possible in the air. However, for studying one of the most challenging problems of space flight—weightlessness—no laboratory was available which could reproduce the phenomenon on the ground.

So the investigators had to go back to a device which they had nearly forgotten as a research tool—the aircraft. Therefore, we have witnessed in the last few years a "renaissance" of the aeromedical experimental aircraft, which actually represents the oldest aeromedical laboratory. Here, we have continued the tradition of the very first acceleration studies, done more than 25 years ago, long before centrifuges were available for testing humans.

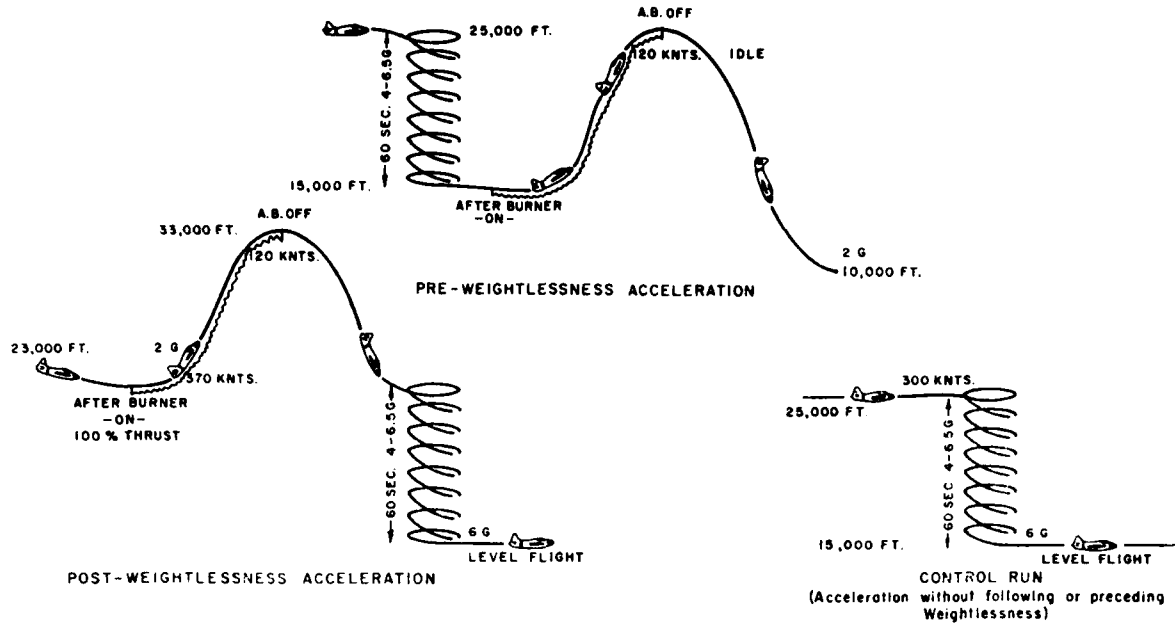
In 1950, Heinz & Fritz Haber gave impetus to these studies by describing theoretically the possibility of producing the weightless state for medical research by flying segments of a Keplerian ballistic trajectory. Soon afterwards, airborne experiments with F-80E, T-33A, and F-94C aircraft were started.

Imaginative Selection of Test Subjects

The investigators proved to be most imaginative in the selection of their test subjects. Besides "cross-marking" and "stylus-aiming" tests on human beings, the ballistic-trajectory flying menagerie included the Rhesus monkey, as well as subtropical water turtles, while not excluding the more common quadrupeds, such as cats, dogs, and rodents.

One of the most intensively studied areas was *neuromuscular coordination* during the weightless state. Several eye-hand coor-

Flight Patterns for Inducing Weightlessness



dination tests were used for this purpose, including cross-marking tests (von Beckh, 1953), and stylus-aiming tests (Gerathewohl, 1956, and Lomonaco, 1956).

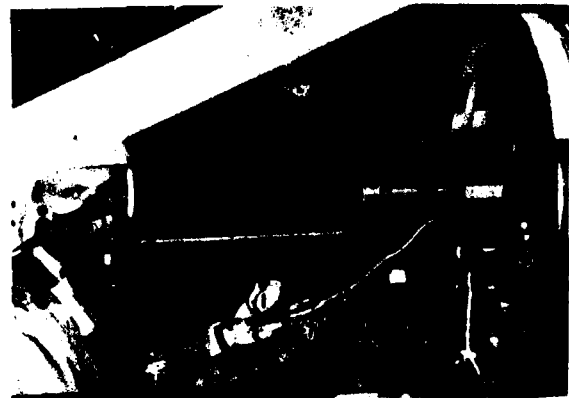
It was shown that neuromuscular coordination deteriorated in the weightless state and led to an "overshoot" in reaching maneuvers. However, the visual control of hand movements was sufficient to compensate for this overshoot and it was found that, after several attempts, aiming movements could be carried out satisfactorily. However, the possibility exists that immediately after burnout, and especially if the operator wants to reach a control without looking at it, he is likely to wind up at the wrong button. Therefore, it is desirable that human engineering experts make controls of space vehicles as foolproof as possible.

The problem of disorientation during weightlessness is very similar. It has been shown that, as long as the subject retains visual references (the horizon or instruments), disorientation rarely takes place. However, in all these experiments the subject was aware that he was about to enter the weightless state and could prepare himself psychologically for this unusual situation.

It seemed of interest, therefore, to observe a subject who finds himself (CONTINUED ON PAGE 84)

Cockpit of F-94C Aircraft With Zero-G

Instrumentation



- | | |
|---------------------|--|
| 1. Recording switch | 5. E.K.G. |
| 2. Aluminum foil | 6. Camera with wide-angle lens |
| 3. Oxygen regulator | 7. Quick-release plugs for electrode leads |
| 4. Oscillograph | 8. Dermo-ohmeter (GSR) |

Weightlessness

(CONTINUED FROM PAGE 27)

in this strange condition without any preparation, as when awakening in the weightless state. Our last series of flight experiments in jet aircraft included just such an experiment. First Lt. C. M. McClure, who shortly afterwards served as pilot of the Manhigh III balloon flight, was selected as the subject. For this weightlessness experiment, he went without sleep for 48 hr. After a full breakfast, which increased his sleepiness, he entered the rear cockpit of our experimental F-94C. He unhooked his headset at 11,000 ft, so as not to be disturbed by the conversation among the pilot, tower, and experimenter. Some 25 min after takeoff, he fell asleep, leaning against the right side of the cockpit. A string was fixed on his left wrist, which the pilot could pull to awaken him. The pilot avoided any rough maneuvers. The aircraft was then flown in a zero-g trajectory and Lt. McClure was awakened.

First Impressions

His first impression upon awakening was that his arms and legs "were floating away from him" so that he felt a desperate need to pull them back toward his body to maintain some sort of normal posture. He tried to hold on to the canopy and some part of the cockpit. He could not orient himself. All this, despite the fact that he is a pilot with over 500 jet hours in the air and never felt such pronounced disorientation before.

Lack of either orientation or coordination can be considered as originated by the weightless state per se. However, more complex problems arise in the transition phase from a one-g or multi-g field to weightlessness, and vice versa. In this transition zone, optical illusions were described, which consisted in the upward and downward movement of a so-called after-image. These have been termed "oculo-agravic" illusions, as described by Gerathewohl and Schock.

In addition, the alternation of weightlessness and high accelerations, as may be expected during the ascent and re-entry of a space vehicle, seems to present hazards by decreasing acceleration tolerance and the efficiency of physiological recovery mechanisms.

In 1953, the author included in an early series of experiments certain flights in which the pullout before entering the weightlessness parabola—which normally does not exceed a 2-g value—was made at high speed and so abruptly that values up to 6.5 g re-

sulted. Control runs were made with the same high-g pullout, but without subsequent weightlessness, and instead were followed by unaccelerated horizontal flight. It was found that blackout lasted longer and discomfort and disorientation were stronger when the recovery from the g-stress took place in the weightless state.

After these early observations, no more airborne experiments on alternation of weightlessness and accelerations were reported, until Soviet IGY data were released about Sputnik II's passenger, Laika. This data noted that "the accelerated heart rate of the animal, produced by the acceleration of the thrust, returned gradually to the normal rate after entry into the weightless state. It took, however,

about three times as long for the number of heart beats to reach their initial values as it did in laboratory experiments, when the animal was subjected to accelerations similar to the launching accelerations."

The aspects of alternate acceleration and weightlessness have today a special importance because this condition will occur during the ascent and re-entry of a rocket vehicle. In biosatellite experiments, the subject will have to endure an accelerative phase from launching until burnout of the engine. The transition from this powered ascent to weightlessness will be very abrupt, since vehicle designers prefer an abrupt burnout to a gradual one. On the other hand, during orbital and space flights, the subject would remain in the weightless state for hours, days, or weeks, and during re-entry would again be exposed to considerable g-loads.

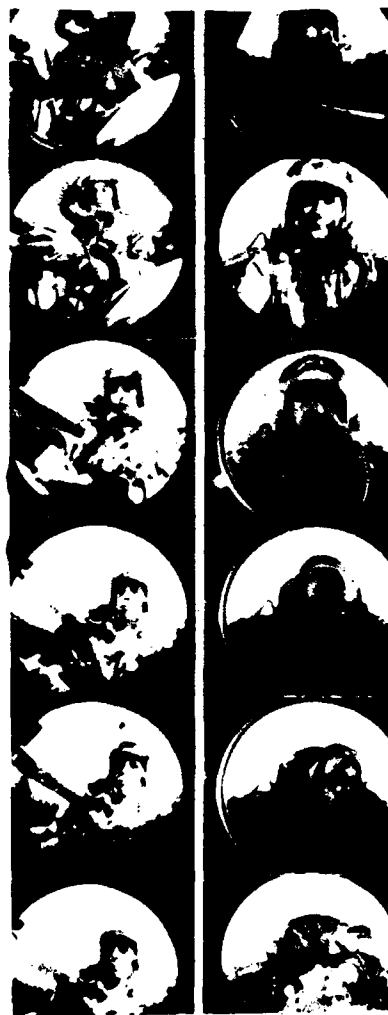
The author, in his early experiments, termed the pattern flown as "post-acceleration weightlessness." However, under these new circumstances, since the reactions to accelerations with preceding or subsequent weightlessness are to be studied, an inversion of the nomenclature seems more convenient, with *pre-weightlessness accelerations* used for the ascent patterns and *post-weightlessness accelerations* for the re-entry patterns.

Jet Aircraft Used in Tests

The author recently conducted experiments with jet aircraft simulating these alternating periods of g-loads and weightlessness. By means of tight, continuous turns, subjects were exposed to positive accelerations of up to 6 g for periods of as much as 1 min. These accelerations produced a pronounced "blackout" of the subject in several cases. Accelerative stress was preceded or followed by a 45-sec Keplerian trajectory which produced weightlessness.

The installation of the bulky recording equipment in the narrow cockpit of the F-94C interceptor was rather difficult, as can be seen from the photo on page 27. The weightless state itself did not cause problems in the functioning of our recording equipment. Instead, the high g-loads interfered with normal functioning of recording devices such as the motion picture camera (jamming of magazines), and necessitated keeping up the structural strength of the instrument rack and equipment mounts.

The subject was instructed to sit upright and to avoid straining or "fighting the g's," while the pilot was protected by an anti-g suit, and was allowed to increase g-tolerance by



Post-weightlessness acceleration brought blackout and severe sub-sternal pain to these two pilots. The top two frames in each strip show the pilot still in the weightless state; the succeeding frames show the onset of acceleration and pilot blackout.

crouching forward. In this way, it was possible to blackout the subject while leaving the pilot in full possession of his senses and in control of the aircraft. The subject was told to describe his impressions and his symptoms via a microphone hooked up both to a miniaturized tape recorder on his left leg and to the aircraft radio system. During each test, the aircraft was in continuous communication with a ground station. The entire conversation was recorded both on the ground and on the subject's tape recorder. This assured preservation of verbal data even in the event of radio failure.

The two-way radio installation also provided an opportunity to initiate some psychological studies. From the ground station, a research psychologist asked test questions, with word-association, inverted number repetition, syllable completion, and drawing tests used. The responses were compared to others recorded both before and

after the flight on the ground. Subjects reported increased susceptibility to or severity of acceleration effects when they entered positive-g states immediately after experiencing weightlessness. Subjects who normally blacked out at 5 g could tolerate only 3.5 to 4 g in the experiments.

In the opposite case, when acceleration preceded weightlessness, physiological recovery mechanisms seemed disturbed. Blackout lasted longer and more severe discomfort and chest pains were reported. Cinematographic observation, registration of heart rate, electrocardiogram, and galvanic skin responses corroborated the subjective reports.

Other problems could arise in space flight of longer duration. Extended weightlessness may very likely lead to lessened muscle tone and strength. Therefore, devices similar to ergometers should be used to exercise the muscles during space travel.

Other inconveniences can be expected for the circulatory system. The heart, used during weightlessness to transport the blood column without the force of gravity, would need a certain time for adaptation after re-entering the gravity field of the earth or another planet.

One example can help illustrate this situation: A person who has been ill and confined to bed for several weeks and then stands up for the first time is likely to experience a so-called orthostatic collapse, because here also the cardiovascular system has lost the ability to compensate for the hydrostatic forces of 1 g.

We can conclude that the greatest significance of zero gravity in space flight will not be difficulties originated by weightlessness per se. Rather, the weightless state aggravates other conditions which, in combination, may pose challenging problems to astronauts.

WEIGHTLESSNESS AND MOTION SICKNESS

In March 1960, at Wright-Patterson Air Force Base, the Symposium on Motion Sickness was held with special reference to Weightlessness (26, 27). This symposium was organized by the 6570th Aerospace Medical Research Laboratories.

The participants are listed in the order in which they spoke.

Dr. W.H. Johnson

Dr. P.K. Smith

Dr. H.I. Chinn

Dr. G.R. Wendt

Dr. S.J. Gerathewal

Maj. J.E. Steel, USAF, MC

Dr. H.J. von Beckh

Maj. W.R. Hawkins

Dr. A.W. Heatherington

Dr. H.E. von Gierke

Lt. J.P. Loftus (Coordinator)

My contribution is reproduced in the paper titled "The Incidence of Motion Sickness During Exposures to the Weightless State" (26). The paper is reproduced in the following:

THE INCIDENCE OF MOTION SICKNESS DURING EXPOSURES TO THE WEIGHTLESS STATE

HARALD J. VON BECKH

USAF Aeromedical Field Laboratory, Holloman Air Force Base, New Mexico, USA

A survey is presented of the results of several investigators who reported human experiments in parabolic flights. It is shown that the incidence of motion sickness is approximately 30 per cent in experiments using fighter aircraft, where the subject is restrained. In cargo aircraft, however, where the subject is unrestrained and able to float within the cabin, the incidence is considerably higher. Several possible explanations for this difference are given. On the other hand, it should be considered that in all parabolic flight experiments the subjects were exposed to accelerations of 2–3 *g* before and after the weightless parabola. In fact, in one series of experiments in which the investigator studied the transition phenomena from high *g* loads to weightlessness and vice versa, peaks of up to 6.5 *g* were produced. It is therefore difficult to distinguish those effects due to acceleration from those due to weightlessness per se. Vagal symptoms at the time of burnout and re-entry would certainly decrease the operator's capability to perform. However, should it be true that weightlessness per se is able to produce motion sickness, then the operator would be liable to suffer vagal symptoms of long duration, which could incapacitate him to a high degree. The applicability of the Weber-Fechner law in this respect is discussed. Bio-ballistic and bio-satellite experiments of increasing duration will provide the answer to this problem before human exposures of long duration will be conducted.

INTRODUCTION

During the last decade extensive studies have been made on the psychophysiological changes which are produced by the weightless state.

Motion sickness did not make its appearance in the very beginning of airborne weightlessness experimentation. This may have been due to the fact that the first humans to experience the weightless state in aircraft had extensive flying background with special experience in aerobatics and other high-*g* maneuvers.

However, as the number of investigators in this field increased and airborne experiments had begun on a broader basis and with more numerous subjects, it was found that several persons experienced vagal symptoms during weightlessness missions.

Paper presented at the Space Medical Symposium, XIth International Astronautical Congress, Stockholm, Sweden, August 15–20, 1960.

Harald J. von Beckh

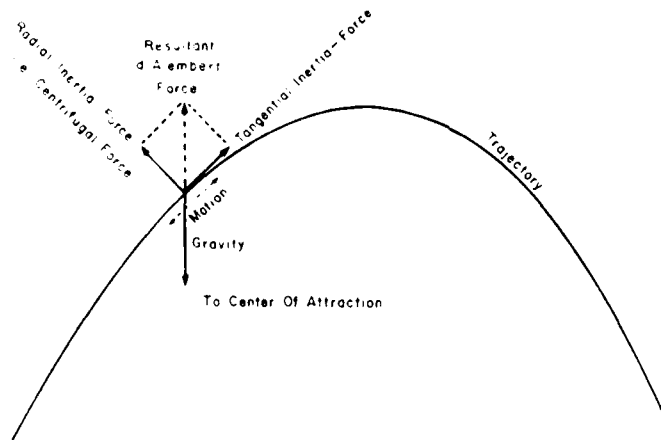


Fig. 1. Classical Keplerian trajectory.

The problem of motion sickness deserves special attention because it constitutes a hazard for manned orbital and space flight. Motion sickness, particularly in combination with other stresses pertinent to space flight, could decrease appreciably the operator's capability to perform and might endanger the completion of the mission.

This report compiles and evaluates observations made during the airborne weightlessness program conducted by the USAF Aeromedical Field Laboratory, which began in September 1954.

Since this date 98 missions, each containing 4 to 8 ballistic trajectories, were flown with 18 different subjects. The aircraft used were the T-33 A, F-89, F-94 C and F-100 F.

METHODS

The first 47 missions used the classical Keplerian trajectory (Fig. 1) as described by Haber and Haber [1]. Virtual weightlessness up to 45 seconds duration was achieved. The initial and final pull-out produced up to 2.5 g.

The problem areas studied were primarily neuro-muscular coordination, oculogravic illusions and postural reflexes under the weightless condition. In January 1958, however, different flight patterns were introduced into this program. Their objective was to simulate the alternation of high g loads and weightlessness and vice versa, as they are expected to occur in human space flight after burn-out and during re-entry. These flight patterns consisted of the usual Keplerian trajectory which was preceded or followed by a diving spiral which produced loads from 4 to 6.5 g for durations up to 60 seconds (Fig. 2).

The following 51 missions employed these patterns and gathered data on

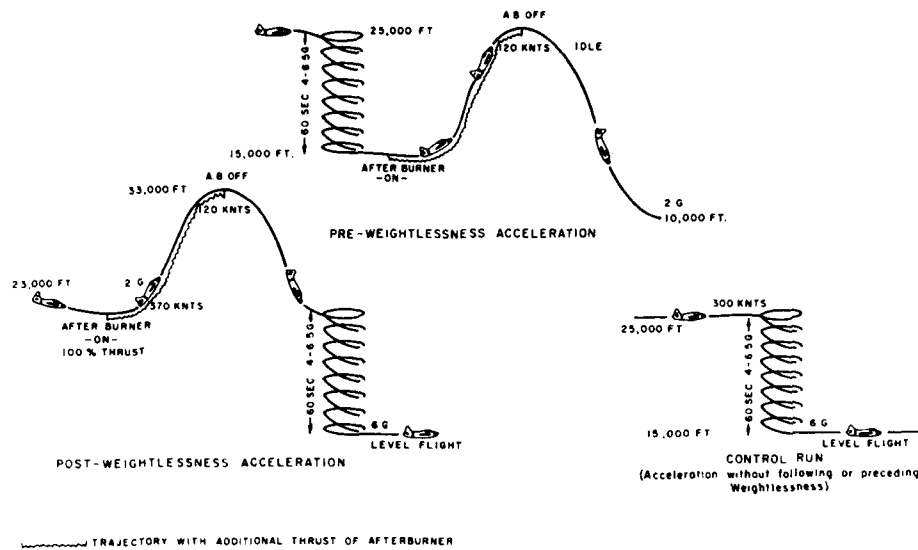
The Incidence of Motion Sickness During Exposures to the Weightless State

Fig. 2. Flight patterns consisting of a Keplerian trajectory preceded or followed by a diving spiral.

human reactions to these pre-weightlessness and post-weightlessness accelerations [2].

INCIDENCE OF MOTION SICKNESS

The incidence of motion sickness in the first and second series of experiments is depicted in Chart 1.

The eighteen subjects included experienced jet pilots, two persons who had never flown previously, and fourteen others of intermediate flying background as pilots or crew members. Subjects 1-9 volunteered for the first series and subjects 8-18 for the second series. Only subjects 8 and 9 participated in both series.

First series: Three of the nine subjects (1, 4, 7) suffered motion sickness of different degrees.

Second series: Four of the eleven subjects (9, 10, 13, 18) suffered motion sickness of different degrees. It is to be noted that subject 9 did not become motion sick during the first series.

DISCUSSION

The incidence of motion sickness in approximately one third of the subjects is the same as reported by Gerathewohl [3], who also conducted his experiments in fighter aircraft.

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Chart 1. Incidence of motion sickness during 98 weightlessness missions.

Subject No.	Flying background	Motion sickness incidence	
Series I			
1	Intermediate	+++	
2	Intermediate		
3	Intermediate		
4	Intermediate	+	
5	Intermediate		
6	Intermediate		
7	Intermediate	+++	
8	Intermediate		
9	Intermediate		
Series II			
		PrWA	PoWA
8	Intermediate		
9	Intermediate	+	
10	No experience	+	
11	Experienced jet pilot		
12	Intermediate		
13	Intermediate	++	+
14	Intermediate		
15	Intermediate		
16	Experienced jet pilot		
17	Intermediate		
18	No experience	+	

Note. The abbreviations PrWA and PoWA show whether motion sickness occurred during pre-weightlessness acceleration or post-weightlessness acceleration patterns. The severity of motion sickness symptoms is depicted by the scale from one to three crosses (+ = nausea, ++ = emesis, +++ = severe emesis).

However, a much higher incidence was observed by Brown [4] and Loftus [5], who conducted weightlessness experiments in the cargo aircraft C-131. These trajectories require initial and final pull-outs of 2 to 2.5 g, whereas the weightlessness duration is only 12–15 seconds.

Several interpretations of these differences come to mind (Chart 2):

a. The subject in the fighter aircraft is tightly restrained within the small cockpit, which is further reduced in size by numerous recording devices (Fig. 3). In the C-131, however, the subject is allowed to float freely (Fig. 4) and is even able to perform some acrobatics like forward and backward somersaults. Additional labyrinthine stimulation is therefore probably present. In addition, in the fighter aircraft the subjects is restrained in the harness of the parachute and tied down by shoulder and lap belts. It is obvious that this restraint would

*The Incidence of Motion Sickness During Exposures to the Weightless State*Chart 2. *Different factors in fighter aircraft and cargo aircraft during weightlessness experiments.*

Fighter aircraft	Cargo aircraft	Factors
Tightly restrained by parachute harness and shoulder and lap belts.	Not restrained. Floating in the cockpit.	"Ballottement" of viscera during acceleration. Additional labyrinthine stimulation during movements in weightlessness.
Continuously busy in moving switches. Has good visibility out of the aircraft. Feels more "part of the aircraft".	No special task assigned. ¹ No visibility out of the aircraft.	Psychologically unoccupied.
Receives through intercom instructions from the pilot, but does not feel observed.	Feels observed by crewmembers and the other subjects.	Anxious not to become sick in presence of others.
	The example of others may induce motion sickness.	Visual, auditory or olfactory stimuli.

¹ This does not refer to several C-131 flights, where the subjects had to perform psychomotor tasks.

diminish the "ballottement" of the viscera, especially of the abdominal organs of greater weight, e. g., the liver.

b. In the fighter aircraft experiments, the subject is busy from takeoff to the landing attending the often rather complex recording devices such as the motion picture camera, the EKG, GSR recorders and other equipment. In addition he retains visibility out of the cockpit, can follow the flight maneuvers and feels, therefore, more a "part of the aircraft" than the free-floating subject in the C-131.

c. In the fighter aircraft the subject hears the voice of the pilot, who gives him instructions, but he does not feel observed by crewmembers and other subjects as in the C-131. The fear of becoming motion sick in the presence of others may in itself precipitate vagal symptoms. In addition, motion sickness can be induced by the example of others through visual, auditory and olfactory pathways.

Comparing the results of series I (low *g* loads) and series II (high *g* loads) one finds that the incidence of motion sickness is approximately the same. However, it would be premature to draw from this fact the conclusion that higher *g* loads would not increase the incidence of motion sickness, because none of the subjects who became sick in series I participated in series II.

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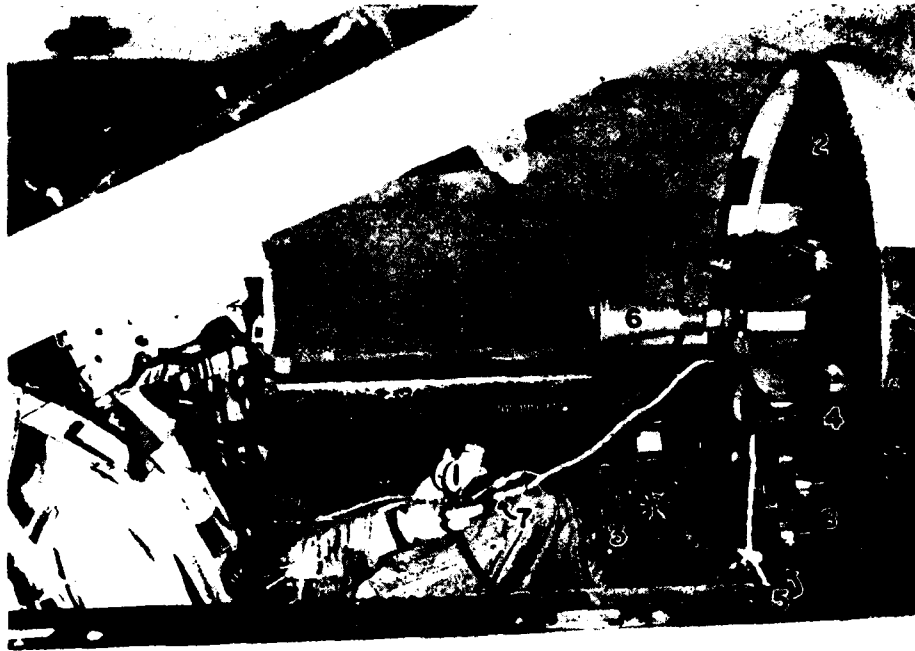


Fig. 3. Sideview of subject's fighter aircraft cockpit showing 0-g instrumentation. 1. Recording switch. 2. Aluminum foil. 3. Oxygen regulator. 4. Oscillograph. 5. EKG. 6. Camera with wide angle lens. 7. Quick-release plugs for leads of electrodes. 8. Dermo-Ohm-meter (GSR).

In addition, the subjects of series II had much more flight experience in toto than those of series I.

In at least one case (subject 1) it could be shown that accelerations were the principal factor in producing motion sickness. This subject invariably suffered unusually severe symptoms. However, by entering and leaving the ballistic trajectory with minimal g loads and avoiding major accelerations in the direction of the trajectory by careful operation of the afterburner, the pilot succeeded in bringing this subject through the parabola without vagal symptoms.

CONCLUSIONS

All weightless phases produced in aircraft are necessarily preceded or followed by phases of increased g s. Controlled weightlessness exposures of humans have, to date, never exceeded durations of approximately one minute. Under these circumstances it is very difficult to separate ill effects caused by accelerations from those caused by weightlessness per se.

The Incidence of Motion Sickness During Exposures to the Weightless State

Fig. 4. Subjects floating freely in a cargo aircraft cockpit.

Therefore, all human experiments until now have revealed the effects of alternating acceleration and weightlessness rather than the effects of weightlessness per se. Accelerations alone may have caused motion sickness symptoms through labyrinthine stimulation and haemodynamic reactions during these experiments.

We can only speculate about the effects of long duration weightlessness on the gravireceptive system. Early investigations in this field [6, 7, 8] suggested that the relationship of stimulus intensity to sensation may be seriously altered under gravity free conditions in accordance with the Weber-Fechner Law.

Although Fechner's logarithmic formulation of Weber's law has been repeatedly criticized and should be accepted only for moderate ranges of stimuli, one cannot exclude the possibility that long duration weightlessness may create a labyrinthine hypersensitivity which could provoke motion sickness through vestibular pathways.

Vagal symptoms at the crucial time of burn-out and re-entry are certainly undesirable and would decrease the operator's capability to perform. However, should it prove to be true that weightlessness per se is able to produce motion

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sickness, then the operator would be liable to suffer vagal symptoms, which would incapacitate him to a high degree and for long durations.

It is difficult to elucidate this problem by experimentation with aircraft because the durations of agravity are too limited. However, it is assumed that in the near future human exposures of increasingly longer durations will be made possible by the use of boost vehicles. If it should then prove true that weightlessness per se can cause motion sickness, adequate countermeasures can be taken at that time.

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CONCLUSIONS

This report contains a number of papers about weightlessness, which were published in the decade 1950-1960, i.e., before manned space flight became a reality.

Although the duration of weightlessness flying parabolic Keplerian trajectories was under one minute, worthwhile knowledge was gained and predictions of long duration weightlessness could be correctly made:

- 1) Weightlessness does not at all provoke a "strong fall reflex" as predicted by Haber and Gerathewohl.
- 2) The lack of neuromuscular coordination is observed only during the first seconds of weightlessness; afterwards the control of the sense of vision allows coordinated movements.
- 3) The incidence of motion sickness was in the Keplerian flights with fighter aircraft, where the subject was tied down and head movements were negligible. However, in the cargo aircraft C 131, where the subject moved freely in the padded cargo department, the incidence was considerable.

In the Mercury project, the astronauts showed limited motion sickness, but when they moved freely in the shuttle spacecraft, motion sickness occurred due to inertial excitation of the labyrinth.

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ANNEX

NADC-85016-60

SPACE-FLIGHT PROBLEMS

Being a complete collection of all lectures held at the Fourth Astronautical
Congress, Zurich, 1953

PROBLEME DER WELTRAUMFORSCHUNG

Vollständige Sammlung der am IV. Internationalen Astronautischen
Kongress 1953 in Zürich gehaltenen Fachvorträge

PROBLÈMES D'ASTRONAUTIQUE

Recueil complet des travaux scientifiques présentés lors du
IVe Congrès International d'Astronautique 1953 à Zurich

*Published by the Swiss Astronautical Society by order of the
International Astronautical Federation*

*Herausgegeben von der Schweiz. Astronautischen Arbeitsgemeinschaft
im Auftrag der Internationalen Astronautischen Föderation*

*Publié par le Groupement Astronautique Suisse d'ordre de la
Fédération Astronautique Internationale*

Printed and Published by: Druck und Verlag: Impression et édition:
Laubecher + Cie - Biel-Bienne (Switzerland - Schweiz - Suisse)

Untersuchungen über Schwerelosigkeit an Versuchspersonen und Tieren während des lotrechten Sturzfluges

Dr. med. H. J. A. von Beckh, Buenos Aires



Das Problem der Schwerelosigkeit und Schwereverminderung ist heute nicht nur für die Raumfahrt, sondern auch für die Luftfahrt bedeutungsvoll geworden, da Steigfähigkeit und Geschwindigkeit moderner Hochleistungsflugzeuge, dieselben, häufiger als bisher, hervorgerufen können:

Die Frage, wie weit Schwerelosigkeit und Schwereverminderung die Orientation des Piloten und seiner Begleiter behindern oder unmöglich machen können, scheint somit wesentlich.

H. von Diringshofen (6)* beschrieb vor dem zweiten Weltkrieg durchgeführte Sturzflugversuche, bei denen Schwerelosigkeit bis zur Dauer von zehn Sekunden hervorgerufen werden konnte und wobei der zunehmende Luftwiderstand durch Motorkraft kompensiert wurde.

* Die Zahlenangaben in Klammern beziehen sich auf die in der Anlage befindliche Bibliographie.

Aquaterrarium mit elektr. Wasser- und Luftheizung. Durch eine Pumpvorrichtung können Wasserströmungen hervorgerufen werden, die bei labyrinthgestörten Tieren Orientierungsstörungen besonders deutlich machen. — Auf einer Rampe können die Tiere auch auf das Trockene kriechen.

F. und H. Haber (14) errechneten die Möglichkeit, mit einem Hochleistungsflugzeug, dessen Kurs einer Parabel mit senkrechtstehender Achse folgt, die Schwerkraft während 20 bis 30 Sekunden aufzuheben.

E. R. Ballinger (1) berichtet über in dieser Form durchgeführten Flüge, bei denen Schwereverminderung und Schwerelosigkeit bis zur Dauer von 20 Sekunden erzielt werden konnte.

Besonders wertvolle Resultate lieferten die Aufstiege der V-2 und Aerobec-Raketen mit Versuchstieren, über die J. P. Henry, E. R. Ballinger, P. H. Maher und D.G. Simons berichteten (16).

Tierversuche

Der Autor beobachtete seit 1951 mehrere *Chelonia*-Arten, die sich besonders gut zu Untersuchungen über Orientations- und Koordinationsstörungen eignen, da sie gewohnt sind, sich im Wasser «dreidimensional» zu bewegen und insbesondere, bei der Nahrungsaufnahme und beim Kampf um einen Köder mit anderen Tieren, eine besondere Geschicklichkeit und Schnelligkeit an den Tag legen.

Ausserdem lieferte der Zufall dem Autor ein labyrinthgestörtes Versuchstier auf folgende Weise:



Hydromedusa tectifera, labyrinthgestört, ohne Behinderung des Gesichtssinns, mit 2 *Chrysemis ornata* auf dem Trockenen. Die 3 Tiere verhalten sich normal.

Vier Versuchstiere (2 *Chrysemis ornata* und 2 *Hydromedusa tectifera*) waren in einem geräumigen Aqua-Terrarium untergebracht, das mit elektrischer Wasser- und Luftheizung versehen war. Während einer zweiwöchigen Abwesenheit des Autors im Som-

Chrysemis ornata und *Hydromedusa tectifera* sind Süsswasserschildkröten der Unterordnung Thecophora. (3)

mer 1952, stellten sich durch einen technischen Mangel (Karbonisation eines Unterbrecherkontaktes) beide Heizungen automatisch ein. — Bei meiner Rückkehr fand ich die Anlage mit einer Wasser- und Lufttemperatur von fast 60 Grad C vor. Die 4 Tiere waren bewegungslos und reagierten kaum.

Beide *Chrysemis ornata*, aus tropischen Gebieten Brasiliens stammend und daher hohe Temperaturen gewöhnt, erholten sich bald und fingen nach 3—5



Hydromedusa tectifera beim typischen Vorschneilen des Kopfes und 8 cm langen Halses.

Tagen wieder an Nahrung zu sich zu nehmen. Die beiden *Hydromedusa tectifera*, aus dem Delta des Rio Parana stammend und daher nur an mässige Temperaturen gewöhnt, verblieben bewegungslos. Das jüngere Tier (♂) verendete nach zwei Tagen. Das ältere Tier (♀) fing nach 3 Tagen an sich zu bewegen und zeigte eine völlige Desorientation, die im Wasser besonders eindrucksvoll war. Der Gesichtssinn war erhalten.

Beim Vorhalten eines Fleischköders versuchte es mit kraftvollen, aber ungeschickten Bewegungen heranzurudern, die in krassem Gegensatz zu seiner sonstigen Geschicklichkeit standen. Das Hervorstechendste war jedoch die Unmöglichkeit, das Hervorschneilen des 8 cm langen, S-förmigen Halses «gezielt» durchzuführen. Der Kopf des Tieres schnellte entweder über, unter oder seitlich an dem angebotenen Köder vorbei.

Nachdem dieser Zustand 2 Wochen angehalten hatte und bereits eine Zwangsfütterung nötig schien, zeigte sich eine ganz allmählich einsetzende Besserung in seinen Bewegungen und später auch im «Anzielen» des Bissens, was nach weiteren 8 Tagen dem Tier gestattete, wieder normal Nahrung aufzunehmen.

Ich nahm damals an, dass der Vestibularapparat des Tieres durch die starke und langanhaltende thermische Reizung eine bleibende Läsion erlitten hatte.

Um das Fortbestehen dieser Läsion zu beweisen, habe ich wiederholt dem Tier, in und ausserhalb des Wassers, eine, mit einem Bändchen fixierte, Kapuze über den Kopf gestülpt.

Das Tier erwies sich als desorientiert und versuchte gar nicht erst, wie die übrigen Tiere mit den Pfoten die Kapuze wegzuschieben. Derselbe Versuch bei den übrigen Tieren zeigte keine Störung der Orientation.



Labyrinthgestörte *Hydromedusa tectifera* mit über den Kopf gestülpter Kapuze. Das bereits vorher optisch kompensierte Tier ist aufs neue desorientiert. Es schwimmt unterhalb der Wasseroberfläche mit dem Bauch nach oben.

So konnte angenommen werden, dass dieses Versuchstier in den 3, der Läsion folgenden Wochen, gelernt hatte, die fehlenden Labyrinth-eindrücke optisch zu kompensieren.

Sturzflugversuche

Im Anschluss wurden mit diesem «adaptierten» Versuchstier, sowie mit einer neu erworbenen *Hydromedusa tectifera* und den beiden *Chrysemis ornata*, lotrechte Sturzflüge durchgeführt, die weitgehende Schwereverminderung und Schwerelosigkeit bis zur Dauer von 7 Sekunden hervorriefen. Auch hier wurde der steigende Luftwiderstand durch Motorkraft ausgeglichen.

Die Tiere wurden in einem zylindrischen Wasserbehälter mitgeführt. Während des schwerelosen Sturzfluges wurde mittels einer Pinzette ein Fleischköder, teils jedem Tiere einzeln angeboten, teils in den Behälter fallen gelassen, wobei die Beobachtung der Tiere im Kampf um den Köder besonders aufschlussreich war.

In normalen Umständen, d. h. im Geradeausflug, bzw. auf der Erdoberfläche, stürzen sich diese besonders gefräßigen species mit Sekundenschnelle auf den Köder, den sie durch das oben erwähnte Vorschnellen des Kopfes schnappen und ausserdem noch versuchen, aus dem Maul anderer Tiere hervorragende Fleischteile zu erbeuten, oder sogar den ganzen Bissen wieder herauszuziehen. Bei den ersten Versuchen wurden die Tiere 2—3 Tage vorher ohne Nahrung gelassen, um ihre Fresslust noch zu steigern,

eine Massnahme, die sich jedoch in der Folge nicht für nötig zeigte. Aus allen diesen Gründen scheinen mir diese Versuchstiere für Beobachtungen, für die nur wenige Sekunden zur Verfügung stehen, besonders geeignet.

Das Resultat der Sturzflugversuche war eindeutig:

Nur die labyrinthgestörte, «adaptierte», *Hydromedusa tectifera* zeigte völlig normales Verhalten, konnte sich orientiert bewegen und frass mit derselben Geschicklichkeit und Schnelligkeit, wie auf der Erdoberfläche.

Die drei anderen Tiere bewegten sich wenig, langsam und unsicher und waren nicht fähig, sich dem Köder zu nähern. Selbst Fleischstücke, die ihnen unmittelbar vor das Maul gehalten wurden, konnten sie trotz bestehender Fresslust nicht schnappen, wegen der Unfähigkeit, das «gezielte» Vorschnellen des Kopfes auszuführen.

In den Horizontalflug zurückgekehrt, verhielten sich alle Tiere normal.

Ferner konnte beobachtet werden, dass nach 20 bis 30 Stürzen die Desorientationssymptome sich verringerten. Es kam jedoch nicht zu einer normalen Nahrungsaufnahme und Bewegungsfähigkeit, wie bei der von vornherein «adaptierten» *Hydromedusa tectifera*.

Zur Beschleunigungsmessung wurden besonders empfindliche, in der Längsachsenrichtung des Flugzeuges angebrachte, Federwagen-Akzelerometer verwendet, die auf die Werte von null bis plus-minus 1 g geeicht waren.

Eine gewisse Schwierigkeit bestand bei den ersten Versuchen darin, dass beim «Andrücken», durch kurzfristig auftretende negative Beschleunigungen, das Wasser (z. T. mit den Tieren) aus dem Behälter in Ovoidform 20 bis 30 cm aufstieg, allerdings zum Grossteil durch Heben des Gefässes wieder in dasselbe zurückkehrte. Mein Plan, einen oben verschlossenen Behälter mit einer besonderen Koedervorrichtung herzustellen, brauchte jedoch nicht ausgeführt zu werden, da das Hochsteigen des Wassers durch eine entsprechende Steuertechnik vermieden werden konnte.

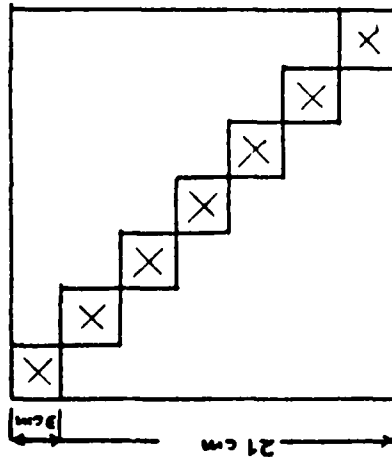
Beobachtungen an Versuchspersonen

Ausserdem wurden Sturzflüge mit Versuchspersonen durchgeführt, wobei ein einfacher Test angewandt wurde, der darin bestand, auf ein, auf fester Unterlage aufgezogenes Blatt Papier (Format 21×21 cm), das die Versuchsperson mit der linken Hand frei festhielt, mit der rechten Hand, ohne den Handballen aufzustützen, in vorgezeichnete, in diagonalen Richtung von links oben nach rechts unten angeordnete sieben Quadrate, Kreuze einzuzichnen. (Siehe Anlage.)

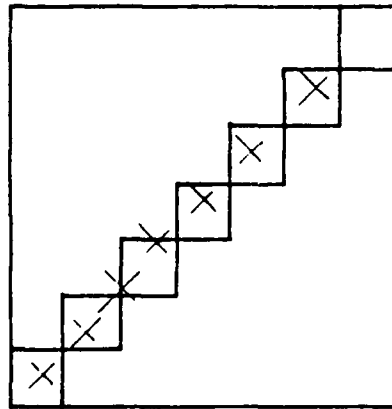
ZEICHEN-TESTE

Im Horizontalflug

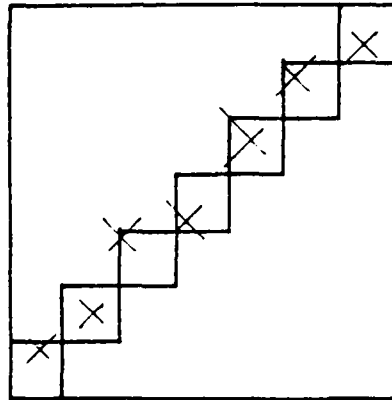
mit offenen Augen



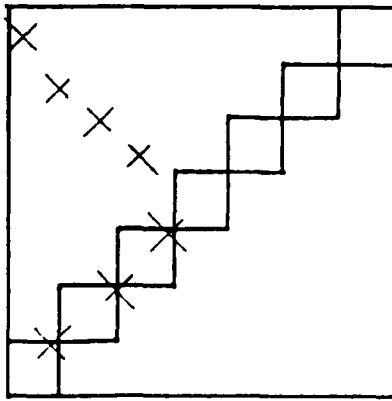
mit geschlossenen Augen



mit offenen Augen

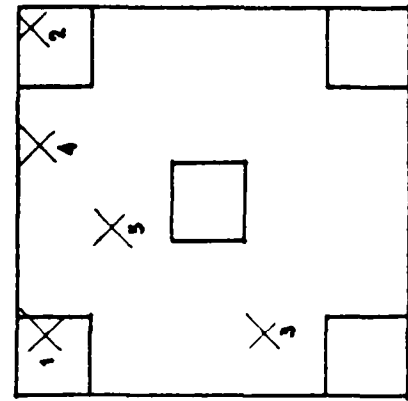
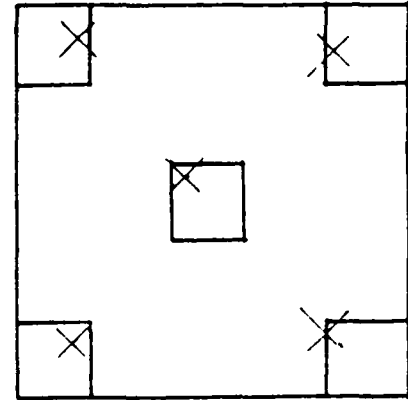
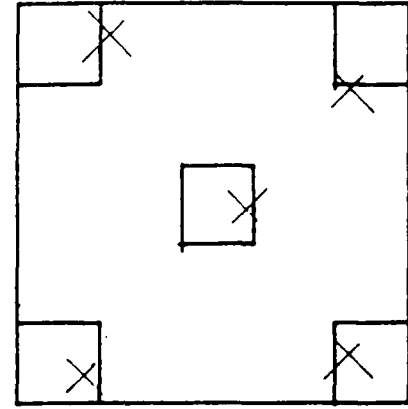
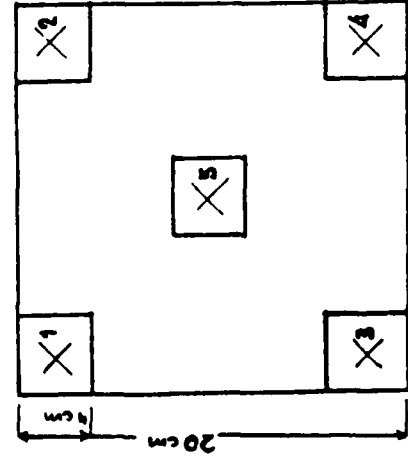


mit geschlossenen Augen



Im senkrechten, schweren Sturzflug

Unten: Ein unter denselben Umständen abgenommener Zeichen-Test. Es wurden mehrere Modifikationen angewandt, die alle identische Resultate lieferten.
(Die Zahlen beziehen sich auf die Reihenfolge der Einzzeichnung.)



Dieser Test, dessen Ausführung nur wenige Sekunden beansprucht, wurde hintereinander, von derselben Versuchsperson 1) im Geradeausflug, 2) bei positiven Radialbeschleunigungen und 3) im schwerelosen Sturzflug, erst mit offenen und anschliessend mit geschlossenen Augen ausgeführt.

Das Ergebnis war eine Verschlechterung des Testresultats bei 2), die bei 3) besonders deutlich wurde und bei Schwerelosigkeit ohne Sicht die völlige Unmöglichkeit, die sieben Kreuze, in einer auch nur annähernd diagonalen, geradlinigen Anordnung einzuzichnen, aufzeigte.

Fast immer zeigte sich nach Einzeichnung des dritten Kreuzes eine typische, etwa 90 Grad betragende, Abweichung nach rechts oben (Beilage).

Auch hier konnte man eine Besserung des Testresultats nach mehreren Stürzen der gleichen Versuchsperson feststellen, die besonders bei einer Versuchsperson, die über reichliche Erfahrung im Instrumentenflug verfügte, schon nach dem zweiten Sturzflug deutlich wurde. Allerdings spielte hier wohl auch ein psychologischer Faktor mit.

Diese Versuche, die zuerst mit straff angezogenen Schulter- und Beckengurten durchgeführt worden waren, wurden anschliessend mit nur locker sitzenden Beckengurten, ohne Schultergurten wiederholt, was eine weitere, merkliche Verschlechterung des Testresultats zur Folge hatte.

Diskussion der Ergebnisse

Die beschriebenen Versuche werden als Beitrag zur Deutung des Zusammenspiels zwischen den Otolithenorganen, dem Gesichtssinn und den kinaesthetischen Rezeptoren, für das Zustandekommen der Orientation und Koordination angesehen, wobei das bereits angenommene Ueberwiegen des Gesichtssinnes, wieder deutlich in Erscheinung trat:

1) Sämtliche normalen Tiere zeigten unmittelbar nach Eintreten der Schwerelosigkeit erhebliche Störungen der Orientation und Koordination, wobei besonders die Unfähigkeit, gezielte Bewegungen des Kopfes und Halses auszuführen, auffiel.

2) Diese, durch die Otolithenentlastung während der Schwerelosigkeit gestörten Tiere, zeigten nach zahlreichen (etwa 20—30) Stürzen eine beginnende Adaptation.

3) Das seit längerer Zeit labyrinthgestörte Tier, das seinerzeit, unmittelbar nach Auftreten der Störung, identische Symptome zeigte, aber nach 3 Wochen sich völlig adaptiert hatte, blieb während sämtlicher Schwerelosigkeitsversuche ungestört.

Schon R. Magnus und A. de Kleyn (18) berichteten, dass beidseitig labyrinthektomisierte höhere Säugetiere (wie Katzen und Affen) bereits wenige Tage nach der Operation normal gingen, sicher kletterten und vor allem «gezielt» sprangen. Hierbei wurde beobachtet, dass sie «unter Benützung der optischen Stellreflexe, das Ziel erst genau mit den Augen aufnehmen, und danach ihren Körper richten».

Hingegen wurde eine Verminderung des Gliedertonus bei ihnen nur vorübergehend festgestellt.

Auch die von mir beobachtete Hydromedusa tectifera führte in der ersten Zeit ihrer Labyrinthstörung ihre Bewegungen nicht mit fehlender Kraft, sondern mit fehlendem Geschick aus, bis sie nach beendeter Adaptation völlig störungsfrei wurde.

Dies erklärt sich durch die Tatsache, dass das Labyrinth auch für die allgemeine Tonusregulation nur ein kompensierbarer Teilfaktor ist.

Allerdings muss man berücksichtigen, dass hier die Adaptation unter Einwirkung des normalen Schwerfeldes erfolgte, was nicht besagt, dass bei lang andauernder Schwerelosigkeit, eine Verminderung des allgemeinen Muskeltonus auftreten kann.

Bei den von I. P. Henry und Mitarbeitern (16) ausgewerteten Raketenanstiegen wurde auch ein Versuchstier (Maus) mitgeführt, dessen Labyrinth vorher durch Elektrokoagulation zerstört worden waren. Wie vorausgesehen, zeigte sich dieses Tier bei Schwerelosigkeit den normalen Tieren überlegen. Bei der Beobachtung dieser Maus, die kinematographisch erfolgte, wurden Orientationsstörungen, aber keine Koordinationsstörungen bemerkt.

Es scheint daher, dass eine Versuchsanordnung mit Wassertieren, denen während der Schwerelosigkeit Bewegungen (wie Annäherung und Schnappen des Köders) «aufgezwungen» werden, besonders geeignet ist, Koordinationsstörungen aufzuzeigen.

Bezüglich des Zeichentests kann zusammengefasst werden, dass auch hier die Bedeutung der optischen Kompensation der ausgefallenen Gravirezeptoren zu Tage trat. Auch im Geradeausflug war selbstverständlich durch Schliessen der Augen eine gewisse Ungenauigkeit im Einzeichnen der Kreuze in die vorgeschriebenen Quadrate festzustellen, doch blieb immer eine geradlinige, diagonale Anordnung erhalten.

Bei Schwerelosigkeit mit Sicht wurden die Einzeichnungen schwerfällig, ungenau und wichen merklich von der Richtung ab, wobei aber die Kontrolle des Auges eine noch halbwegs diagonale Anordnung ermöglichte.

Bei Schwerelosigkeit ohne Sicht war die Abweichung von der vorgeschriebenen Richtung jedoch so stark, dass sie in keinem Verhältnis zu der gewohnten Verschlechterung bei Schliessen der Augen stand. Die oben erwähnte starke

Abweichung nach rechts oben (Skizze) könnte, wie mir H. von Diringshofen mitteilte, durch ein Ueberwiegen des Tonus der Anheber in der Schwerelosigkeit, hervorgerufen sein.

Es scheint, dass Störungen des Muskelgleichgewichts bei positiven Beschleunigungen leichter ausgeglichen werden können, als bei negativen Beschleunigungen. Dies entspräche dem Weber-Fechner'schen Gesetz*, das besagt, dass bei einem Beschleunigungszuwachs von 1 auf z. B. 4 g sich das Gewicht nur um das vierfache verändert, während die Relation bei Herabsetzung der Belastung von 1 g bis zum Schwellenwert des Gravitationsreizes, der noch nicht genügend bekannt ist, jedenfalls sehr viel grösser ist.

Die Bedeutung der Sinneseindrücke des Hautdrucksinns für die Orientation im Fluge wurde schon von S. Garten (10) betont.

H. Strughold beschrieb einen Selbstversuch, bei dem er, nach Anaesthesierung beider Nervi glutaei, beim Fliegen das sonderbare Gefühl hatte, dass die Maschine unter ihm wegglikt. (21)

Auf diese Weise liegt es nahe, dass man durch festes Anschnallen, bei Schwerelosigkeit, über die Rezeptoren des Hautdrucksinns die Orientation wesentlich erleichtern kann, was auch aus dem oben beschriebenen Zeichentestversuch hervorging.

Es ist vorgesehen, diese Testflüge fortzusetzen und weiterzuentwickeln. Einerseits könnte man mit einem Schwenksitz, versehen mit einer Vorrichtung, die erlaubt, den Kopf in verschiedenen Stellungen und Richtungen zu bewegen und fixieren, unterschiedliche Reaktionen, entsprechend den verschiedenen Ausgangslagen der Otolithenorgane beim Uebergang in die Schwerelosigkeit auslösen. Andererseits könnten durch einen modifizierten Test, lohnende Resultate im Sinne der von S. J. Gerathewohl vorausgesehenen, optischen Sinnestäuschungen gewonnen werden.

Eine weitergehende physiologische Auswertung dieser noch laufenden Versuche ist für eine spätere Veröffentlichung vorgesehen.

In diesem Zusammenhang möchte ich noch hinzufügen, dass neben kongenitalen Taubstummen ohne Labyrinthfunktion, sich für derartige Versuche, auch streptomyzingeschädigte Versuchstiere und eventuell auch durch lange therapeutische Streptomyzingaben geschädigte Patienten eignen würden.

K. Berg (2) und P. Northington (19) berichten über die selektiv toxische Wirkung des Streptomyzins auf den Vestibularapparat.

K. Berg injizierte zweimal täglich 25 Katzen während eines Zeitraums von 14—127 Tagen Streptomyzin, dessen Gesamtdosis auf einen erwachsenen Men-

schen bezogen, 156—965 g entsprach. Der Labyrinthausfall wurde durch Aushleihen des Diehnystagmus festgestellt. Der pathologisch-anatomische Befund ergab degenerative Veränderungen des Sinnesepithes der crista ampullaris und der maculae des sacculus und utriculus. Das Corti'sche Organ zeigte jedoch mit Ausnahme eines Tieres, das die höchste Streptomyzindosis erhalten hatte, keinen pathologischen Befund.

P. Northington beobachtete 56 Patienten. Dosierungen von täglich 2,5—3,2 g riefen bereits in der zweiten Woche Labyrinthstörungen hervor, die durch Drehversuche und thermische Reizung nachgewiesen wurden. Tagesgaben von 1 g wurden jedoch, mit einer Ausnahme, während 75 Tagen störungsfrei vertragen.

Die Wirkung langandauernder Schwerelosigkeit auf den menschlichen Organismus wird wohl erst durch die Raumfahrt völlig geklärt werden können.

Was Orientation und Koordination betrifft, kann man jedoch voraussehen, dass infolge der optischen Kompensation keine wesentlichen Schwierigkeiten bestehen werden. Insbesondere Flugzeugführer mit Erfahrungen im Instrumentenflug, werden sich besonders schnell adaptieren, da sie bereits gelernt haben, den Sensationen von Seiten der Gravirezeptoren zu misstrauen, um sich nur auf ihre, durch den Gesichtssinn wahrgenommenen Bordinstrumente zu verlassen.

Die Möglichkeit, dass langandauernde Schwerelosigkeit sich auf den Blutkreislauf durch Ausschalten der Regulationen der haemostatischen Niveauunterschiede ungünstig auswirken würde, sowie, dass im Adaptationsstadium Beschwerden im Sinne der Luftkrankheit auftreten können, wurde schon von berufenerer Seite besprochen.

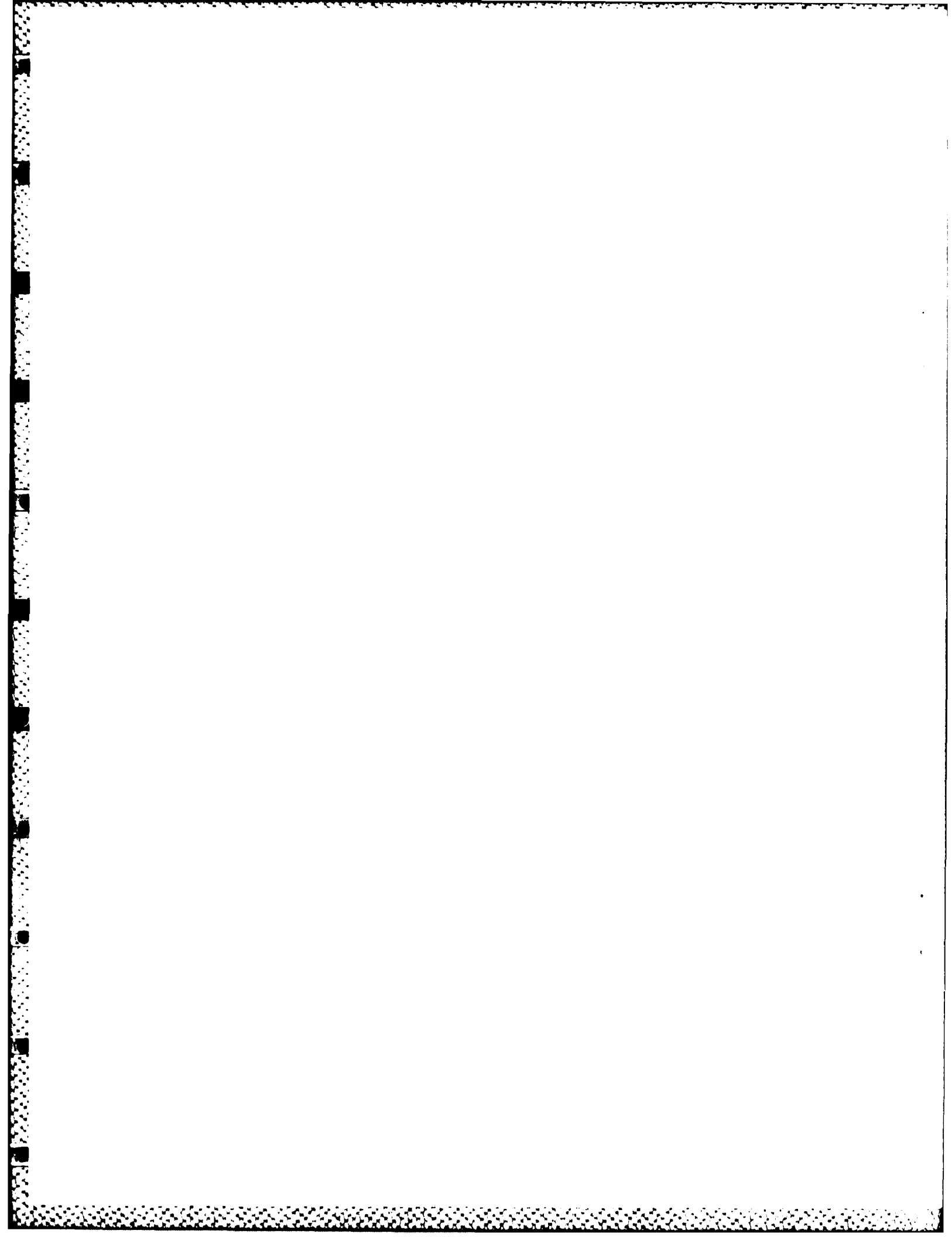
Wenn man aber andererseits die bekannten, bereits detailliert durchdachten Projekte, durch zentrifugale Beschleunigungen eine «synthetische» Schwerkraft zu schaffen, in Betracht zieht, kann man abschliessend annehmen, dass das Fehlen der Erdschwere nicht als grundsätzliches physiologisches Hindernis der Raumfahrt angesehen werden kann.

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* Weber-Fechner'sches Gesetz: Die Intensität eines Sinneseindrucks ist proportional dem Logarithmus der Intensität des auslösenden Reizes.

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